SR-2

Providence Harbor Improvement Spoil Disposal

Site Evaluation Study - Phase II

S. B. Saila, S. D. Pratt, and T. T. Polgar

Marine Experiment Station

University of Rhode Island

Kingston, Rhode Island 02881

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INTRODUCTION, SUMMARY, AND RECOMMENDATIONS

Introduction

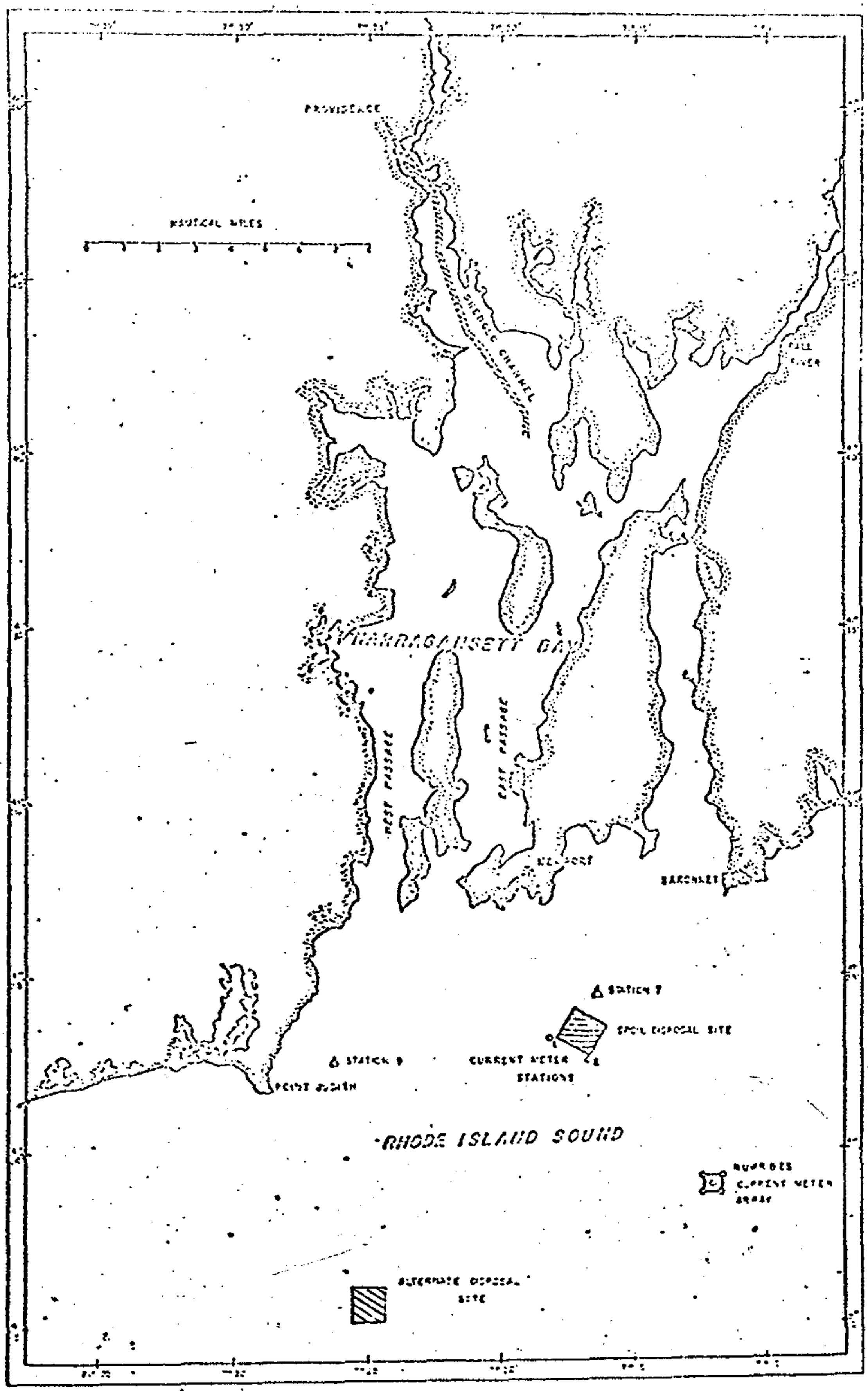
Between December 1967 and September 1970, 8.2 million cubic yards of dredge spoil from the Providence River were deposited on an offshore site in Rhode Island Sound.

The Providence River Improvement Project of the United States Army Corps of Engineers involved the use of a bucket dredge to deepen the navigation channel to Providence, Rhode Island from 35 to 40 feet. The areas dredged included Providence Harbor, a series of reaches extending about 5 miles down the Providence River, and a 2 mile long approach channel in upper Narragansett Bay (Figures 1 and 14).

Although much of the material removed from the Harbor consisted of recently deposited silts of the type handled by maintenance dredging, a ...e volume of the spoil consisted of compact sands and silts deposited before the estuary was significantly affected by man's activities. This relatively dense and cohesive material contrasts strongly with the fluid silt-clays deposited by suction dredges in Chesapeake Bay and described by Harrison (1967) and Briggs (1970).

The spoil was carried to sea in scows of 2,000 and 3,000 cubic yard capacity and discharged within a one square mile dumping area, approximately ... miles south of Newport, Rhode Island. The depths in this area were between 96 and 106 feet before dumping began.

This was the first time that dredge spoil from Narragansett Bay had been dumped offshore rather than within the estuary. Reasons for this included: 1) the large volume of spoil, approximately 10 million cubic ...s for the completed project; 2) the knowledge that spoil dumped within estuaries is often transported back to the dredged channels; and 3) the



ig. 1 General location map for Narragansett Bay and Rhode Island Sound.

wing concept that estuaries are valuable recreational and fisheries resources incompatible with use as spoil dumps.

Background information about the choice of the offshore site appeared in an initial study of dredge spoil dumping in Rhode Island Sound (Saila, Polgar and Rogers, 1968). That study provided limited predisposal information on the dump site, some short-term tolerance studies of locally important marine organisms, a calculation of spoil volume on the site, and turbidity measurements during dumping operations. In general, the outcome of the early work suggested that minimum damage to natural resources had occurred up to the end of the project period, when 1.96 million cubic yards had been dumped.

The present study which was carried out between March and September, 1970 was designed to bring physical observations up to date, to examine aspects of dredge spoil dumping not explored in the first study, and to reach general conclusions about the response of benthic invertebrates to environmental disturbances.

The contracted objectives of this study were:

1) to reassess by bathymetry the observed distribution of spoil material after 5.5 million cubic yards had been discharged on the dump site;

2) to relate observations of the speed and direction of bottom currents in the vicinity of the site to observed and potential spoil movements;

3) to make observations on the species composition and abundance of benthic invertebrates on the dump site and surrounding areas, to assess the effects of the spoil dumping on these animals, and to predict the nature of recovery of the area after dumping ceases.

To these contracted objectives have been added:

1) a bathymetric survey after 8.2 million cubic yards had been dumped,

2) an examination of the sediments of the spoil and of the dump ite area,

3) a.description of the fisheries in the dump site area.

Some information included in this report was collected by University f Rhode Island personnel during 1969. This work was supported by the arine Experiment Station of the University of Rhode Island as part of a ontinuing program of studies on marine resource utilization.

Although the emphasis of this study was on aspects of spoil disposal hich relate to the management of a specific offshore area, information btained on the composition of the benthic assemblages of Rhode Island ound and on the colonization of new sea bottom by benthic animals is of eneral ecological importance.

Future decisions on the use of the continental shelves for mining and umping will require integrated studies dealing with benthic ecology, edimentary geology, and hydrography. This study is an example of such a rogram on a limited scale.

ummary

I. Disposition of spoil on the dump site - The disposition of spoil as determined by two bathymetric surveys and two series of sediment samples. hese determinations were checked by sub-bottom profiles and by diver bservations. The following results and conclusions were reported.

1) Within the limits of the precision of the bathymetric surveys, the volume of dredge spoil on the disposal area was the same as that reported dumped. No large scale loss had taken place during or after the dumping operation.

2) A layer of incohesive silt-clay covered much of the dump during the summer of 1970, indicating a non-erosive hydrographic regime during that period.

3) In July 1969 the spoil formed a low cone centered in the middle of the disposal area.

4) In October 1969 and September 1970, the spoil formed a cone 16-18 feet high and about a mile in diameter centered near the west corner of the disposal area. The spoil extended from 1/4 to 1/2 mile outside the designated disposal area to the NW and SW.

5) Spoil from Providence Harbor containing a high percent organic matter was deposited during the early part of this project. This has been covered by less organic spoil from the lower Providence River except outside the dumping area to the NW and inside the dumping area along the NE edge.

6) Patches of spoil were found as much as a mile outside the dump site toward the NW and SW.

II. Sediments of the dredging and disposal areas - The sediment types found in the Providence River, in Rhode Island Sound, and in the dumped spoil were described on the basis of published information and the analysis of a small number of representative samples. The following results and conclusions were reported.

1) The sediments in the dump site area were well sorted fine sands. They were yellow or olive colored and contained about 1% organic matter.

2) The dredge spoil included sediments which had been deposited in various environments within the present estuary and under various post-glacial environments. These sediments included polluted silts containing up to 12% organic matter, unpolluted estuarine silty sands with shells and pebbles, and varved sands and clays deposited in glacial outwash.

3) Although much of the spoil had a smaller median grain size and a higher % organic matter than the natural sediments in the dumping area, these were not always distinguishing characteristics. Poor sorting and the presence of the shells of estuarine mollusks were more reliable indicators. Clay, pebbles, plant detritus, oil globules, and grey or black color were also used to identify spoil.

4) Soft silt/clay mantling the spoil surface appeared to be much less resistant to erosion than the sand outside the dumping area. Denser mixed sand/silt/clay appeared to be relatively erosion resistant. Coarse fractions were found in most the spoil samples which could form protective lag deposits after some erosion has taken place.

III. Characteristics of the physical environment - The physical char-cteristics of the dump site environment were described on the basis of: review of recent studies on Rhode Island Sound circulation, 2) bottom urrent measurements near the dump site during periods of high tidal velocity, id 3) review of regional wave data and predicted wave induced velocities t 100 foot depths. The probability of erosion and transportation of spoil as examined on the basis of experimental results in the literature and of he sedimentary characteristics of the spoil. The following results and onclusion were reported:

1) Currents in the dump site region were dominated by the semidiurnal tide. Instantaneous bottom currents rarely exceeded 0.3 knots, whereas the net tidal transport velocity was no greater than 0.1 knots.

2) Currents alone were not effective in resuspending sediments.

3) Waves in the area could develop bottom velocities sufficient for the resuspension (erosion) of unconsolidated sediments for a

significant fraction of the time.

4) The mode of deposition and mechanical characteristics of dredged materials apparently resulted in an erosion resistant disposition. The dumped material could not be considered unconsolidated, and theoretical predictions based on the behavior of unconsolidated sediments were not applicable.

5) It was concluded that beaches in the region should remain free of dredge spoil traces from the dump site.

IV. Review of some direct effects of spoil dumping on marine animals - Possible effects of spoil dumping were examined on the basis of published information and a single burial experiment. An attempt was made to identify those effects which would be significant in the Rhode Island Sound environment. The following conclusions were reported:

1) Burial - A few benthic species are able to reach the surface after deep burial (over 20 cm). Although some offshore mollusks may have limited mobility compared to analagous estuarine species, most benthic species around the dump site can probably reach the surface after shallow burial.

2) Turbidity - Many marine animals including fish species and lobsters can withstand very high concentrations of suspended sediment for short periods. It is doubtful that any mortality has resulted from turbidity in the dump site area. The effect of turbidity on the feeding efficiency of filter feeders and on the behavior of fish is not known.

3) Anoxia - Although lack of oxygen in spoil sediments may restrict the colonization of infauna, the overlying water probably never becomes anoxic.

4) Hydrocarbons - Hydrocarbons have been detected in some spoil samples and in some Providence River sediments, but are not considered to be a serious problem on the dump site. The hydrocarbons appear to be mainly biologically inactive compounds and most of the exposed spoil consists of sediments with low hydrocarbon content. It is possible, however, that some spoil has hydrocarbon levels high enough to affect the chemical senses of benthic animals.

5) Heavy metals - Toxic metals are probably present in some Providence Harbor sediments. The levels of these metals in the surface sediments of the spoil dump are not known, although it is likely that little metal containing spoil is exposed. Detritus feeding infauna and their predators would be most likely to concentrate such metals.

6) Change in grain size distribution - It is difficult to predict the effect of a change in grain size distribution on the make-up of the benthic community at this location. Hydrographic conditions, which will remain unchanged, may continue to determine the species found.

V. The effects of spoil dumping on the benthic fauna of Rhode Island Sound - Macrobenthic invertebrate assemblages were examined in the spoil source area and in undisturbed areas of Rhode Island Sound. Analysis was based on a limited number of quantitative 1/10 M^2 bottom samples. Qualitative grab samples served as a check on the representativeness of the 1/10 M^2 samples. A similarity index was used to compare samples. Faunal diversity index values were calculated and their usefulness as indicators of environmental disturbance examined. The following results and conclusions were reported:

1) A small number of pollution resistant benthic species were found in Providence Harbor. Although low oxygen seemed to be the major stress, toxic substances are probably also present in this area.

2) Over thirty benthic species were found in the lower Providence River. These indicated a relatively low level of pollution in that part of the spoil source area.

3) Several species were found on the spoil dump which had been transported from the dredge area. The only abundant transported species which seemed well adapted for Rhode Island Sound conditions was _Nephtys incisa_, a polychaete occurring there naturally.

4) The natural faunal assemblage on sandy sediments in the spoil dump area was dominated by _Ampelisca agassizi_, a tube building amphipod crustacean. Dense mats of _Ampelisca_ tubes determined sediment quality and provided a habitat occupied by subdominant species.

5) Much of the spoil was recently dumped and had few animals on it. However, some surfaces which had been exposed to colonization for between one and three years yielded large numbers of species (up to 53 per 1/10 M^2 sample). The presence of these animals indicated that these spoil surfaces lacked gross toxic or repellent properties.

6) Although the spoil was generally silty, only a few colonizing species were recognized as being members of the offshore silt bottom assemblage. Lack of information on the presence of the larvae of these species in the overlying water, made it difficult to ascribe this absence to sediment properties, however.

7) Most of the species colonizing the spoil were members of the surrounding sand bottom assemblage. Several species of deposit feeding polychaetes and an amphipod crystacean, _Leptocheirus_

pinguis, were found in greater abundance on the spoil than in their natural habitat.

8) *A. agassizi* was found on some spoil areas indicating that colonization was independent of the quality of underlying sediment where the hydrographic regime is suitable. It seemed likely that this species would eventually dominate the spoil as it did the surrounding area. It was not possible to estimate the time hwich would be necessary for the establishment of this dominance.

9) Although the faunal assemblages sampled in this study had characteristic diversity index values, these could not be simply interpreted. Some spoil samples had relatively high values indicating little disturbance, while the natural *A. agassizi* assemblage had extremely low values.

10) Several of the species which were abundant on the colonized spoil have been reported to be used as food by commercially important fish.

VI. Fisheries resources in the dump site area - Interviews with commercial fishermen from Newport, Rhode Island were used to determine the types of fisheries in the dump site area and the extent to which each was affected by the spoil dumping. Summaries of information on the three major fisheries follow:

1) Trawling for fin fish is carried on E and SE of the dump site during winter and spring and N and NE of the dump site during summer and fall. The winter fishery for cod and flounder was successful in 1970. The summer fishery for butterfish and scup has been relatively unsuccessful for several years. It is believed that this was due to natural variations in abundance. The major

concerns of trawl fishermen were that spoil might be dumped outside the designated area and that spoil would increase turbidity after storms, reducing fish catchability.

2) Lobstering is carried on throughout Rhode Island Sound in the summer. Most lobstermen avoided trapping near the dump site for fear of low or polluted catches, burial of traps, and loss of buoys. One fisherman, however, made good catches on the perimenter of the dump site during 1970. It is believed that these lobsters entered the spoil area during normal movements. Lobstering was the least affected fishery and will probably be carried out on the spoil after dumping ceases.

3) The dump site is located near the center of a discrete patch of ocean quahogs which were not being utilized at the time that dumping began. During 1970 these were dredged from areas on the perimeter of the dump site. Animals which had been killed by burial were recovered from the inshore edge of the dump site and from a location on which spoil was dumped before the present dump was approved.

Recommendations

I. Dump site management - The following recommendations are made for future use of this site for disposal of spoil which is acceptable on the basis of ecological and public health standards.

1) Special attention should be paid to accurate placement of the spoil. A possible method of monitoring the accuracy of placement would be to require tow boats to carry recording fathometers. A record of each trip would prove that the dump site had been reached since the profile the present spoil mound is easily recognizable.

2) Spoil should be dumped in the center and in the N and E part of the site in order to cover relatively organic spoil and to prevent further transgression outside the site to the S and W.

3) Dredging projects which include a variety of sediment types should be planned so that either unpolluted or coarse materials are dumped in a pattern which buries polluted or very incohesive materials.

4) Dredging and dumping techniques should be used which deliver spoil to the bottom with minimal suspension and loss of compaction. Large bucket dredges and large hopper scows are indicated.

5) Large volumes of incohesive fine grained sediments should not be dumped at the site until the possibility of erosion and transport by wave induced bottom currents has been investigated further.

6) Future surveys of the dump site should include an area at least 1/2 mile outside the designated area. Improved navigation and profiling systems should be utilized in volume measurements. Spoil should be identified on the basis of poor sorting, the presence of shells of estuarine mollusks, high percent volatile material, and high percent silt-clay.

7) A permanent record should be kept of the volume, sediment properties, and placement of all spoil dumped on this site.

II. Geological research - Studies in the following areas would provide information of value in planning utilization of the continental shelves for mining and cable laying as well as for disposal of various materials.

1) Laboratory and field studies should be carried out on the velocities necessary to erode spoil sediments both with and without populations of tube building animals.

2) Near-bottom wave induced velocities should be monitored on the present site and on proposed alternate sites. Rapid response solid state velocity sensors would be necessary for such studies.

3) The suspension of sediments from the bottom during storms should be studied. The maximum density and time course of settling should be described over various natural and spoil covered bottoms.

4) Surface sediment parameters on the present dump site should be monitored for several years in order to detect loss of fine fractions and the development of a lag deposit.

5) The extent to which sediments deposited from suspension contribute to the spoil extending outside the designated area should be determined. The presence of horizontal structures and graded beds will reliably indicate this type of deposition.

III. Biological considerations and research

1) Dumping of spoil from unpolluted areas should be allowed on the present disposal site. With accurate dumping no areas outside the designated zone should be affected. Colonization of the spoil by benthic organisms should begin soon after dumping ceases.

2) No spoil from polluted areas should be dumped on this site until more information is available on the possibility of the transfer of toxic substances and pathogenic microorganisms from spoil to species eaten by man.

3) Any ocean sites should be closed to fishing while spoil from polluted source areas is being dumped. Such sites should not be reopened to fishing until a complete check has been made of possible health hazards.

4) A program should be initiated which will consider the possibilities

of transfer of toxic substances from spoil dumped at sea to human food. The present dump site could be used as an experimental area and model for such a program. Areas of concern would include:

a) toxic metals present in the sediments of the spoil source area and the disposal area,

b) toxic metals present in selected animals from the dump site, including detritus feeding polychaetes, predators, and species eaten by man

c) concentration factors of metals from prey to predator.

This information should be considered in relation to the surface area of polluted spoil exposed on the dump site, the resistance of spoil to erosion, and the depth of reworking by burrowing animals. The longevity of important pathogens in seawater and the biochemical stability of organic pollutants are additional areas of concern.

5) The colonization of the spoil on the present site should be monitored for several years. When this study was conducted, the spoil surface was physically unstable and colonization had only begun on the edges of the site. The characteristics of the sediment and the specific makeup and productive capacity of the fauna will continue to change for several years. Continuing studies will benefit from the taxonomic work of the present study.

6) Laboratory studies should be made on the effect of burial and high turbidity on selected offshore benthic species.

IV. Alternate disposal sites

The present disposal site appears to be well chosen on the basis of minimal disturbances to regional fisheries and minimal erosion of spoil.

There is area available within the site for a large volume of additional spoil. Continued use of this site for disposal of relatively cohesive and unpolluted material is preferable to the establishment of a new site in near-shore waters.

Sheldon Pratt

Alternate sites should be considered, however, in the event that the present site is judged as unsuitable for the disposal of polluted spoil or of large volumes of incohesive fine grained spoil.

"The area which appears most suitable for the location of a permanent disposal site for Rhode Island and southern Massachusetts is approximately 50 miles from the mouth of Narragansett Bay at a depth of 210 feet. This area is centered at 70°55'W and 40°40'N at the edge of an existing munitions disposal site.

The continental shelf within the 180 foot contour supports an intensive trawl fishery. However, outside this area fish abundance decreases markedly. During 1969 no catches of bottom fish were reported from within 10 miles of the suggested alternate dump site location by boats based in Point Judith, Rhode Island (National Marine Fisheries Service, 1970). The offshore lobster fishery is concentrated on the continental shelf edge which is about 45 miles from this location. A developing ocean quahog fishery is located inshore of this area.

The presence of relict silty sediments in this area indicates that little erosion or transportation is taking place (Garrison and McMaster, 1965, McKinney and Friedman, 1970). McClennen (1971) calculated the expected velocities of wave induced bottom currents on the New Jersey continental shelf using Airy wave theory and the wave records of Hogben and Lumb (1967). Velocities capable of eroding fine sand (15 cm/sec) would be expected 17 percent of the time at 120 foot depths but only 3 percent of the time at 240

If it is considered technically or economically feasible to dump in this area in the future, a preliminary study of the hydrography, geology, benthic ecology, and fisheries potential of the area could be carried out on the basis of available information. Such a study would allow an initial decision to be made on the suitability of the location and would serve as a basis for future field surveys.

ymetry

Bathymetric maps of the disposal area were prepared as a basis for the determination of the volume, distribution, and bulk properties of the spoil. It was considered desirable to map the area with a precision of $\pm$ 0.5 feet because of the small vertical dimensions of the spoil mound. An error of one foot in depth measurement over the one square mile dumping area would represent a volume of 1.3 million cubic yards. Although it was possible to determine depths with the required precision with the sonic depth recorders used in this study, completion of accurate maps was made difficult by problems in navigation and by rough seas.

None of the navigation techniques used during this study were completely satisfactory. Double sextant angles to shore points gave satisfactory accuracy, but required a large survey team and a visibility of approximately six miles. Loran did not have the precision required for this type of survey. Radar navigation with the dump site marker bouys as targets could only be used during periods without wind or strong tidal currents which would cause the survey vessel to make leeway.

Another problem which was met in preparing bathymetric maps was a difficulty in separating waves and bottom features on the depth records. On rough days these had nearly the same amplitude and wavelength.

The original bottom in the general region of the dump site slopes toward the SW (Fig. 2). Within the disposal area a four foot high ridge strikes SE-NW across this slope (Fig. 3-1). A large fraction of the spoil was deposited on the SW side of this ridge (Fig. 9-3, 10-2). Low ses 1-2 feet high and approximately 1/8 mile wide are found throughout

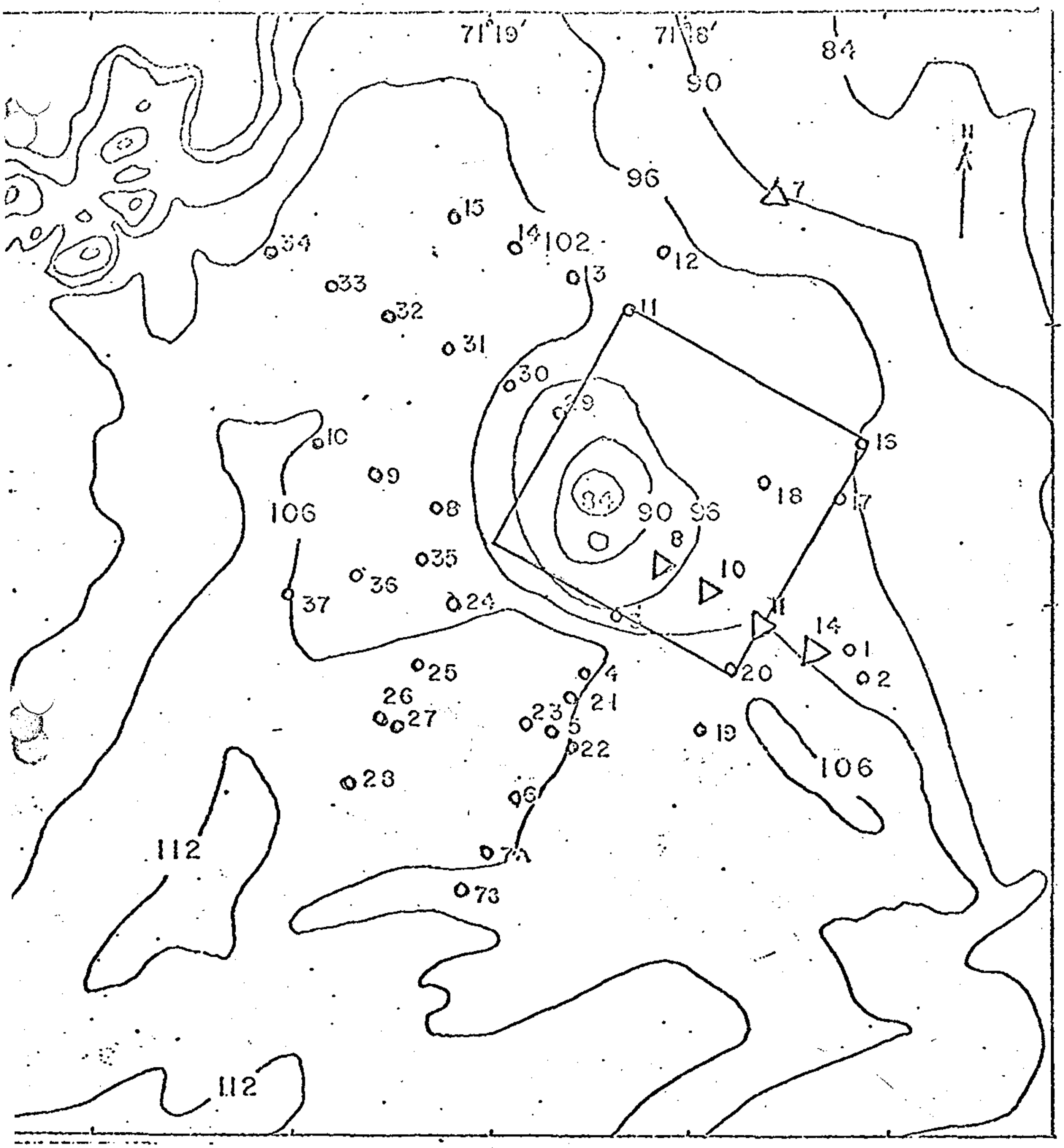


Fig. 2. Location map of the spoil dump area. The one square mile designated dumping zone is outlined. Depth contours in feet are derived from C. & G. S. Bathymetric Map 0808N-51 and from a survey of the dumping zone September, 1970. Sample locations are shown for single grabs (circles) and for triplicate 1/10M^2 Smith-McIntyre grabs (triangles).

he area. Volume changes were calculated by subtracting the depths obtained after a period of dumping from those determined before dumping began. The precise registration of these maps was of considerable concern since large apparent volume changes would result if the maps represented different areas of the sloping bottom.

Figures 3-1 and 3-2 (from Saila, Polgar and Rogers, 1968) show the depth contours from surveys made previous to dumping and in July, 1968 after 1,960,000 cubic yards had been dumped. Figure 4 shows the contours of equal thickness of added material (isopachs) obtained by the subtraction of these depths. The spoil was distributed in a cone centered in the middle of the dump site. This pattern probably resulted from dumping near a central buoy in place at that time. Much of the material shown on this map came from Providence Harbor. It is believed that the negative values in the east corner of the dump site were due to mapping error and not to erosion.

Figure 5 shows the depth contours obtained on October 22, 1969 utilizing the Army Corps of Engineers 105' tug, the Manomet. The quality of the depth records from this survey was diminished by four foot high waves superimposed on the bottom trace. The isopach map is shown in Fig. 5. Spoil volume calculated from this map gave an estimate of 5.46 million cubic yards. The volume reported dumped at that time was 5.5 million cubic yards.

Figure 7 shows the depth contours obtained on September 25, 1970 utilizing the R/V La Nina, a 50 foot trawler operated by the University of Rhode Island. Calm seas permitted unusually good resolution of bottom features. The isopach map for this date is shown in Fig. 8. Calculated volume was 8.3 million cubic yards while it was estimated that 8.2 million cubic yards had been dumped at that time.

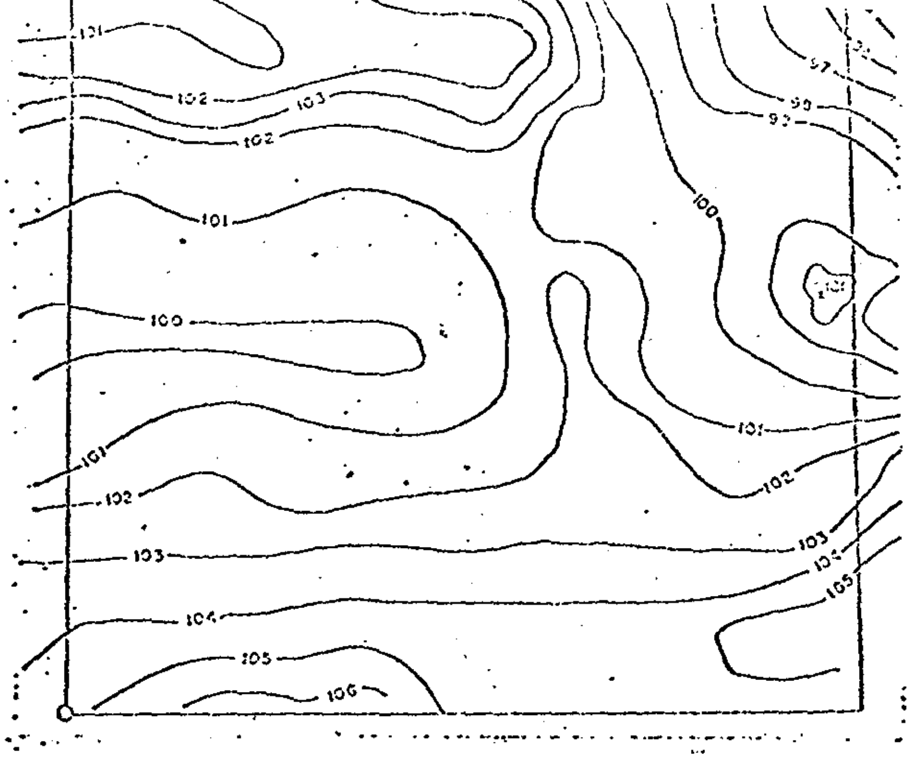


Fig. 3-1. Contoured bathymetry of the dump site previous to dumping. The contour interval is 1 foot. (From Saila, Polgar and Rogers, 1968).

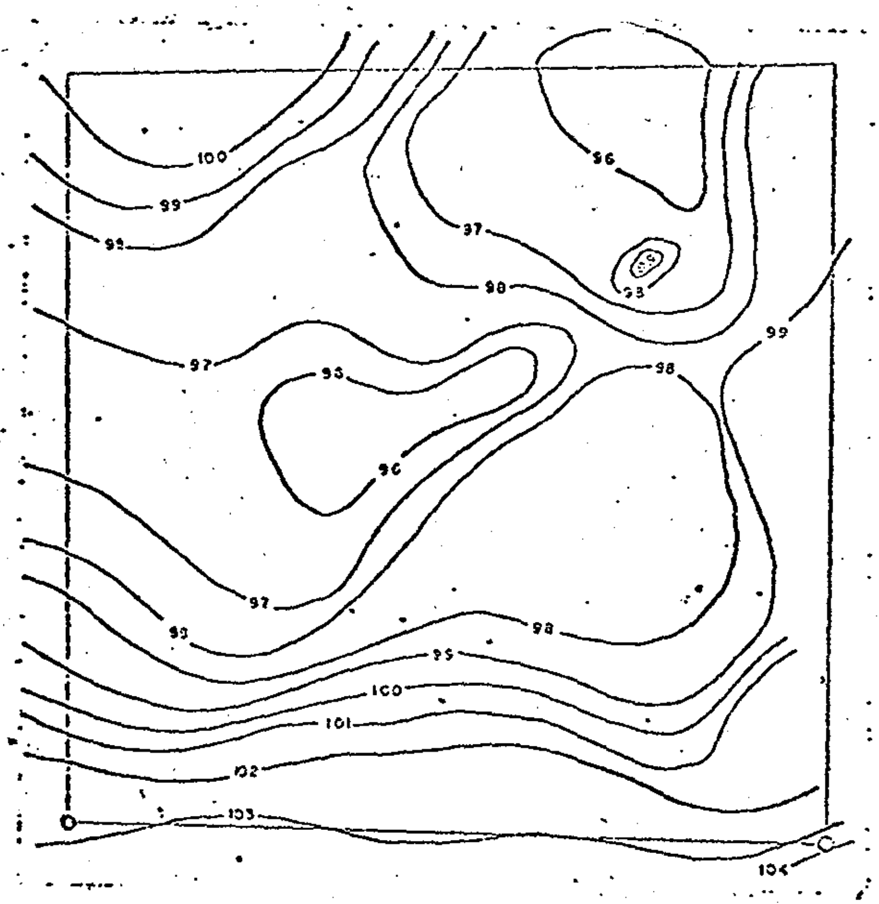


Fig. 3-2. Contoured bathymetry of the dump site from a survey made in July 1968 after 1.980,000 cubic yards had been dumped. Contour interval is 1 foot. (From Saila, Polgar and Rogers, 1968).

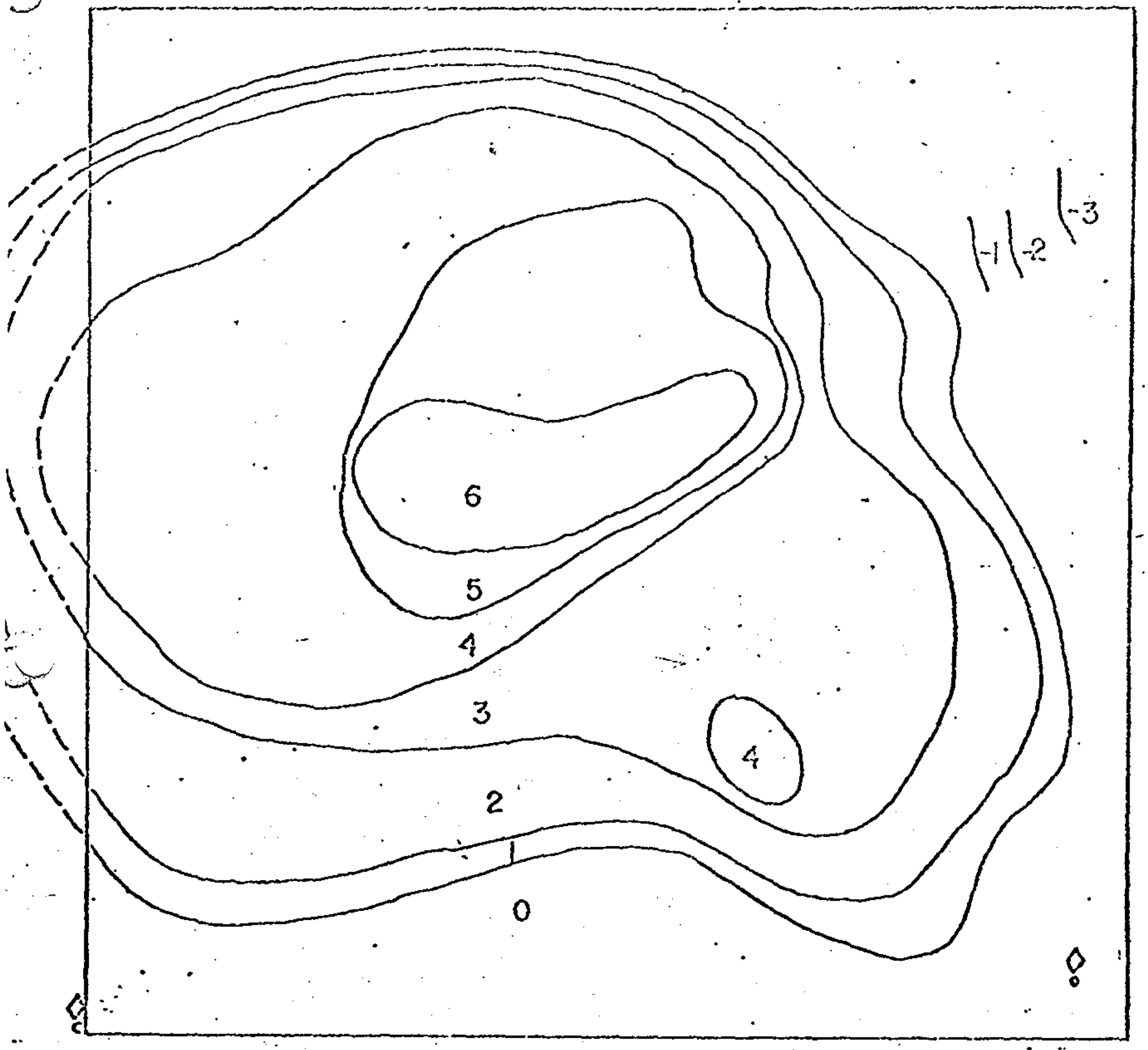
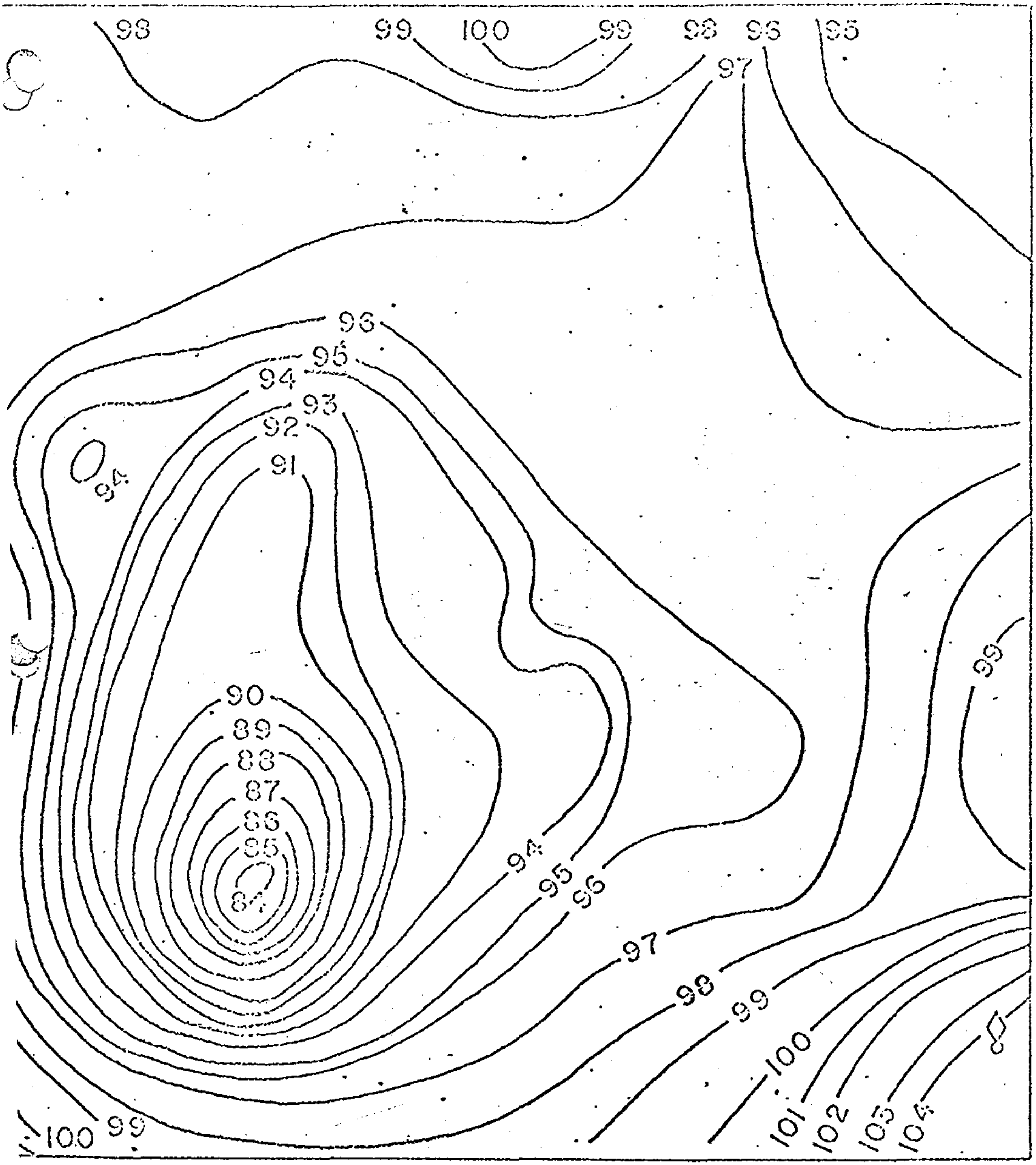


Fig. 4. Isopach map of dump site representing the difference between depths prior to dumping and after 1,960,000 cubic yards had been dumped. The contour interval is 1 foot. (Map redrawn from data of Saila, Polgar and Rogers, 1968).



g. 5. Contoured bathymetry of the dump site from a survey made October 22, 1969 after 5,500,000 cubic yards had been dumped. The contour interval is 1 foot.

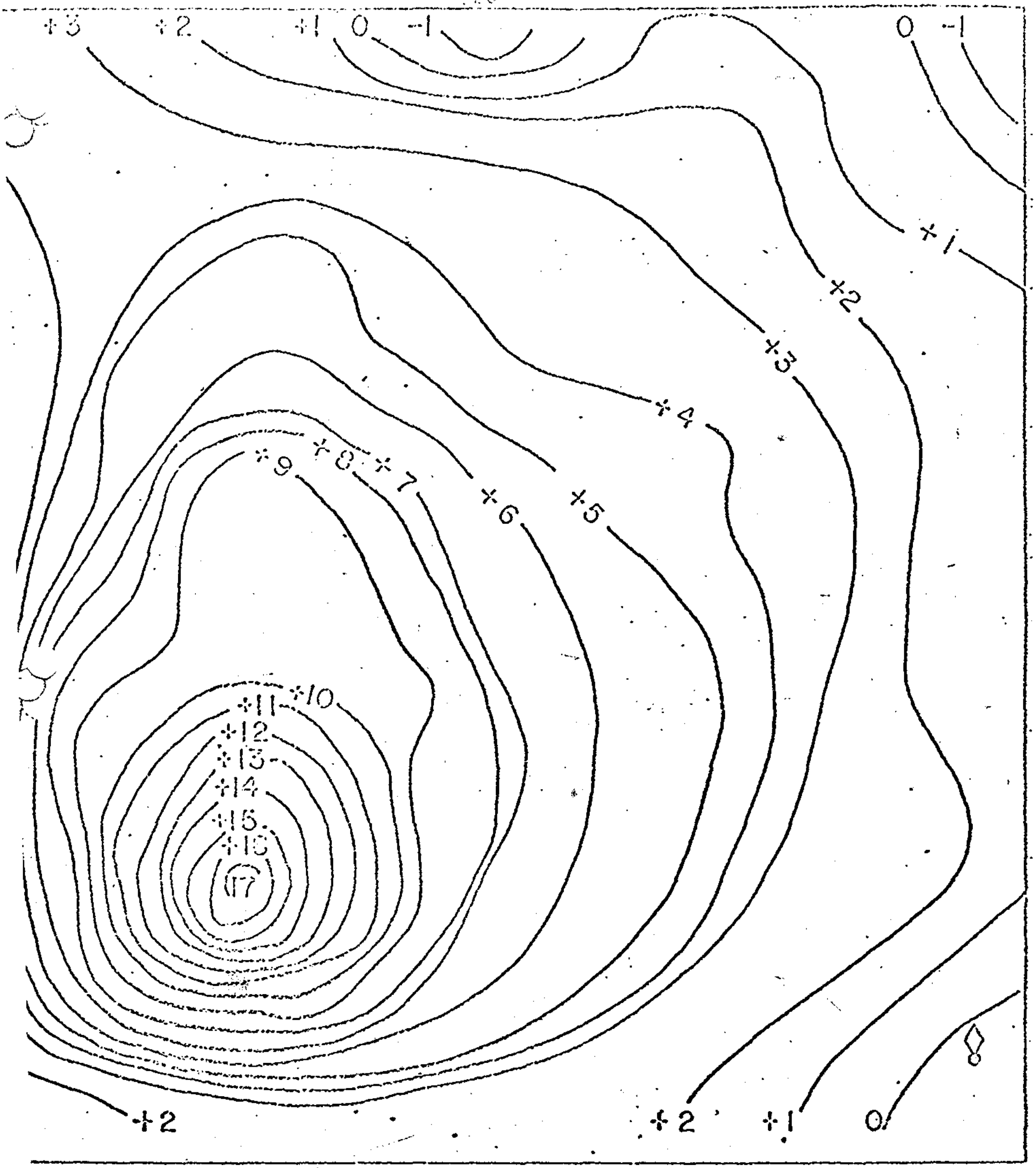


Fig. 6. Isopach map of dump site, representing the difference between the depths prior to dumping and after 5,500,000 cubic yards had been dumped. Calculated spoil volume is 5,460,000 cubic yards. The contour interval is 1 foot.

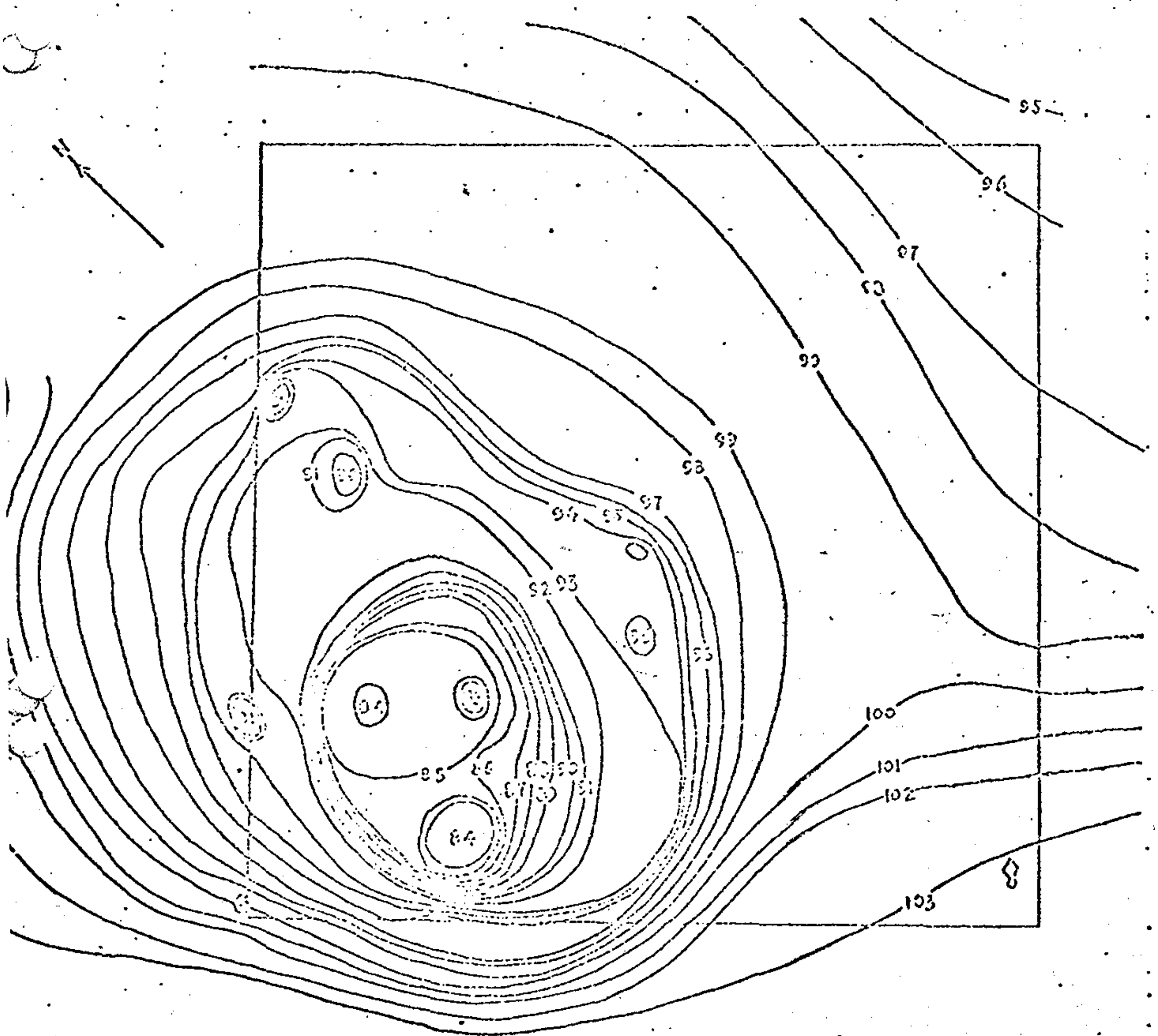


Fig. 7. Contoured bathymetry of the dump site from a survey made September 25, 1970 after 8,200,000 cubic yards had been dumped. The contour interval is 1 foot.

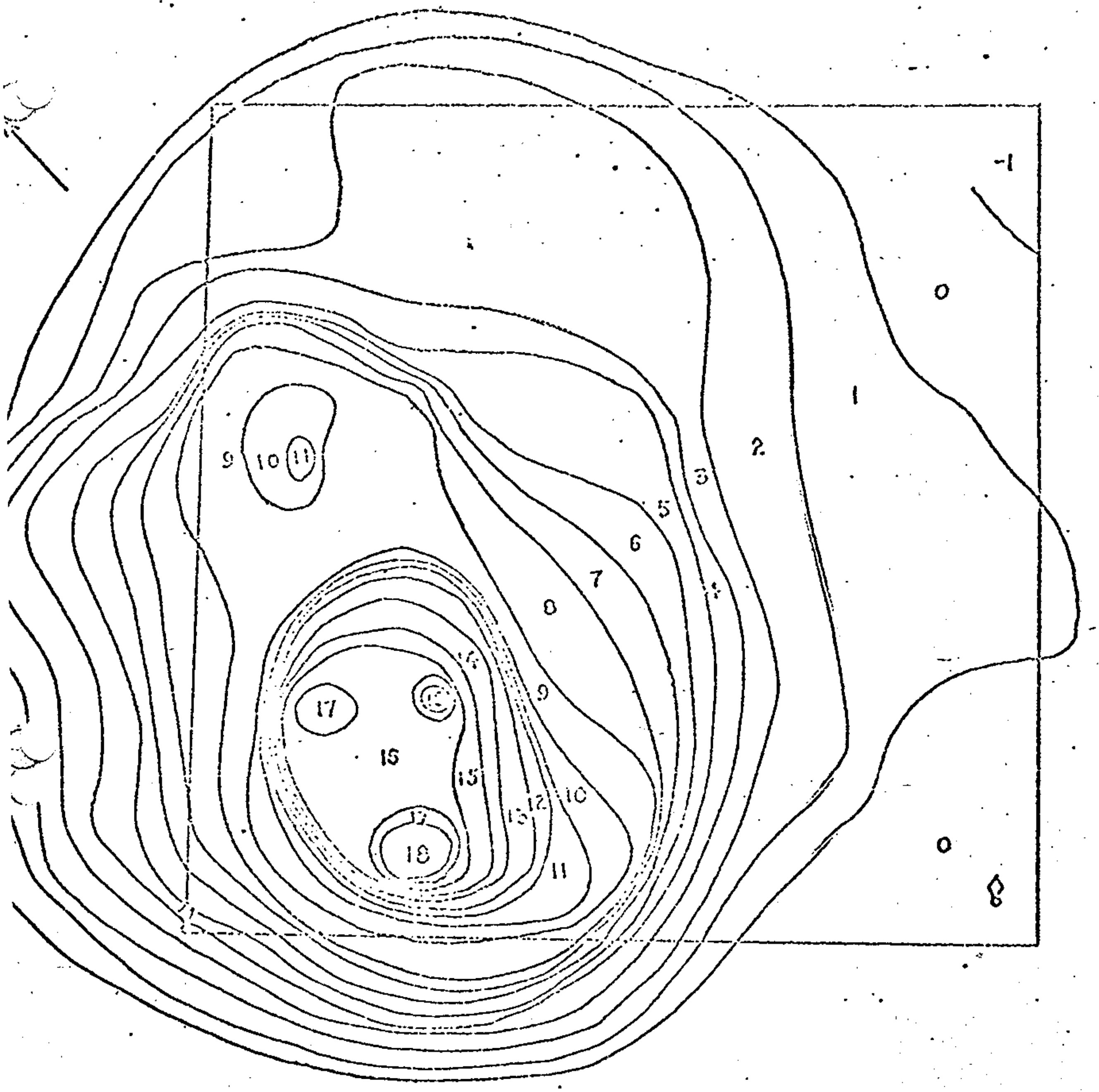


Fig. 8. Isopach map of dump site representing the difference between the depths prior to dumping and after 8,200,000 cubic yards had been dumped. Calculated spoil volume is 8,300,000 cubic yards. The contour interval is 1 foot.

In the two surveys just discussed the spoil was found in a low zone centered 1/4 mile from the west corner of the dump site and extending slightly outside the designated dumping area to the NW and SW. This pattern reflects unloading of barges close to the west corner following the placement of the bouys presently marking the S and W corners. Areas on the N, NE, and E edges of the dump site had received little added material since the 1968 survey.

Estimates were made of the characteristic slopes of the spoil from examination of the September, 1970 depth records, three of which are shown in Figs. 9-1, 9-2, and 9-3. Small relatively steep mounds with slopes of approximately 2° 30' are believed to represent single barge loads of dense spoil from recent dredging operations. They are about 100 feet across and 3 feet high. A large scale feature of the spoil "pile" is a central cone with a 1° slope. This "angle of repose" results from the combined effects of dumping pattern, impact of the spoil with the bottom, gravity flow of fluid sediments, slumping of compact sediments, and erosion and transport by waves and tides. Slopes less than 1° are found around the perimeter of the site. These may be constructed of suspended sediments which have flowed to the base of the cone. Cores in these areas would be expected to show nearly horizontal strata and graded beds.

The technique used in mapping spoil thickness in this study required accurately positioned bathymetric surveys both before and after dumping. An alternate method would be necessary in mapping spoil in areas where no previous survey had been made. It was considered worthwhile to examine the utility of high resolution near sub-bottom profiling in obtaining simultaneous traces of the spoil surface and the original bottom.

The Ocean Systems group of the Raytheon Submarine Signal Division

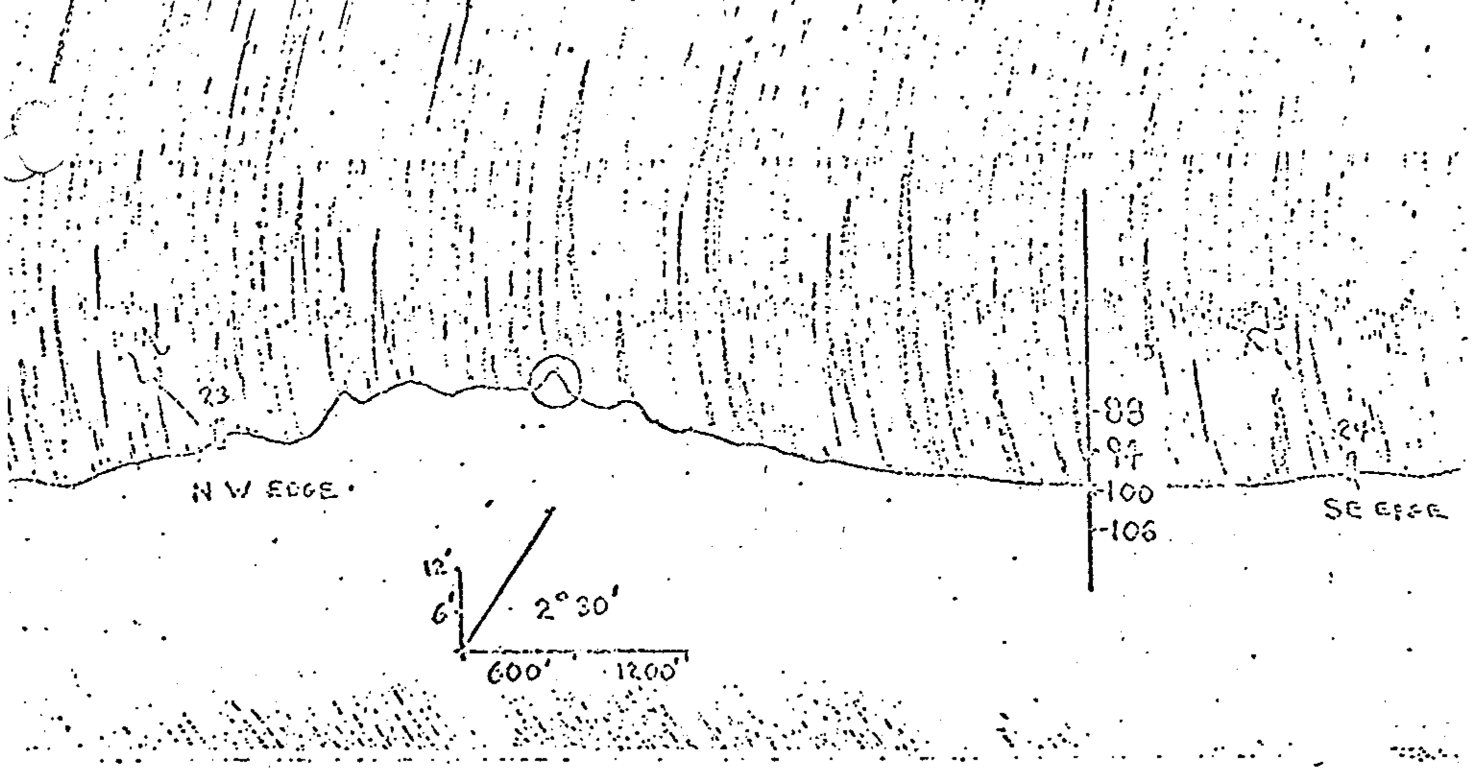


Fig. 9-1. Echo sounder record of a NW-SE traverse over the highest part of the spoil 1/4 mile from the SW perimeter of the designated dumping zone. The spoil is up 18 feet thick. The feature circled has a 2° 30' slope and probably represents a single barge load.

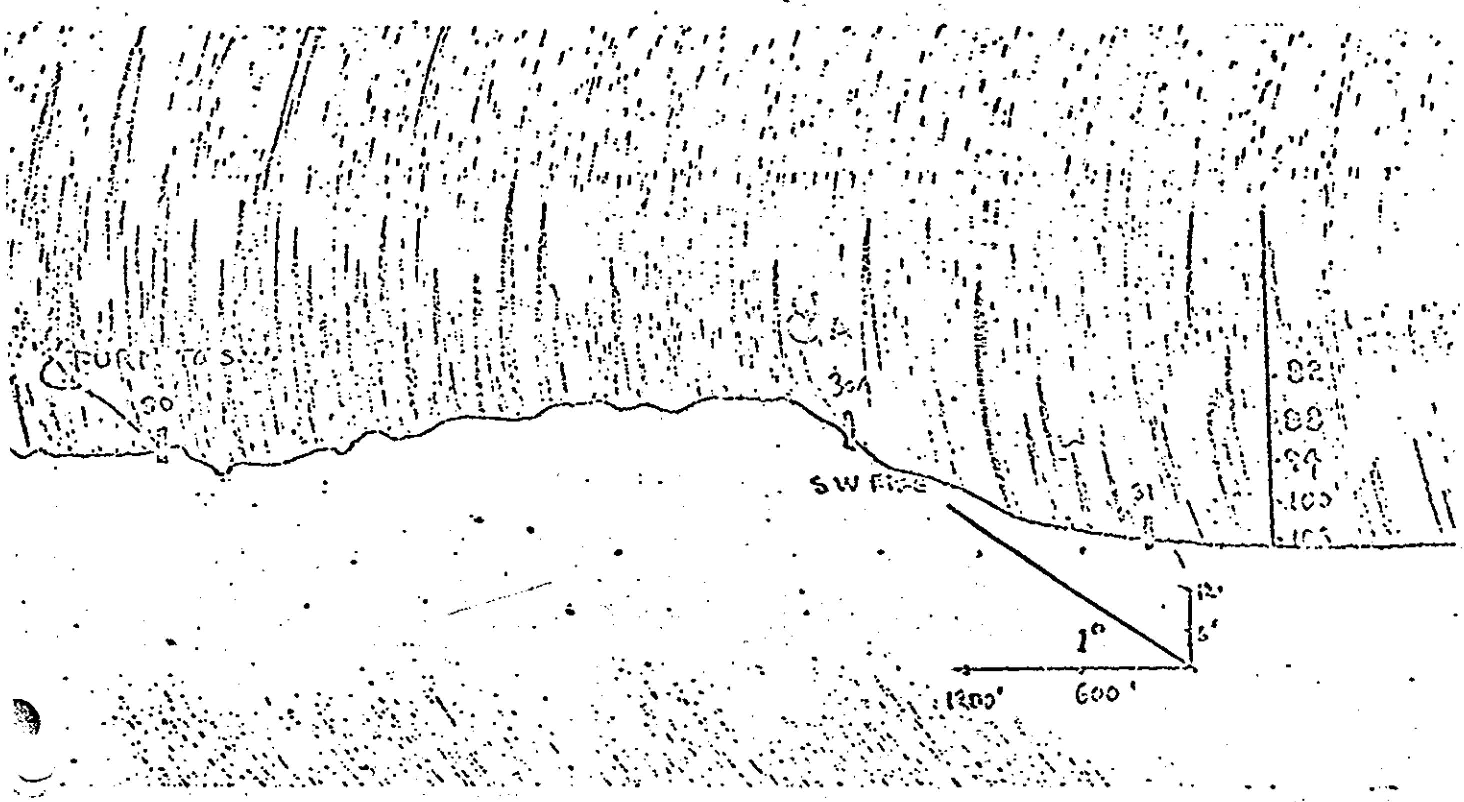


Fig. 9-2. Echo sounder record of a NE-SW traverse over the highest part of the spoil 1/4 mile from the NW perimeter of the designated dumping zone. This section is at a right angle to that shown in fig. 9-1. The slope on the SW edge is about 1°.

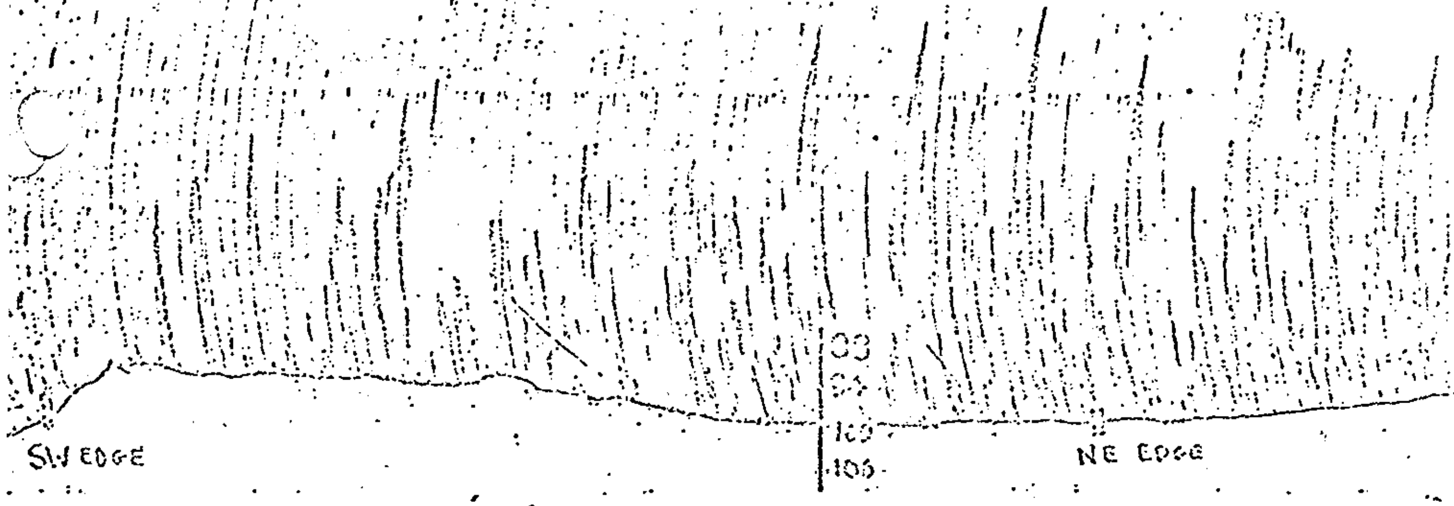


Fig. 9-3. Echo sounder record of a SW-NE profile bisecting the designated dumping zone. The general slope of the original bottom dips toward the SW.

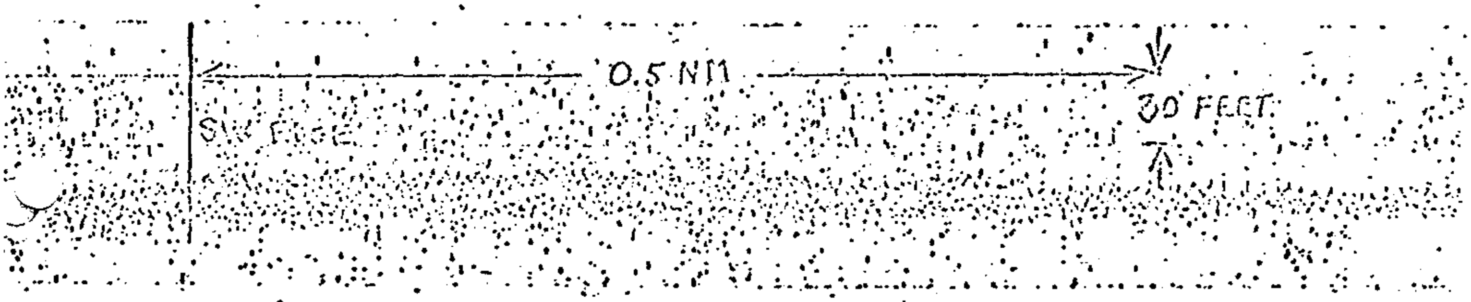


Fig. 10-1. Near subbottom profile of a SW-NE traverse 1/4 mile from the NW perimeter made with the Raytheon FACT/CESP system (2°-3° beam, 1 KH_z). This section is the same as that shown in Fig. 9-2. The original bottom can be seen under the spoil. Waves about six feet high give the record a sawtoothed appearance.

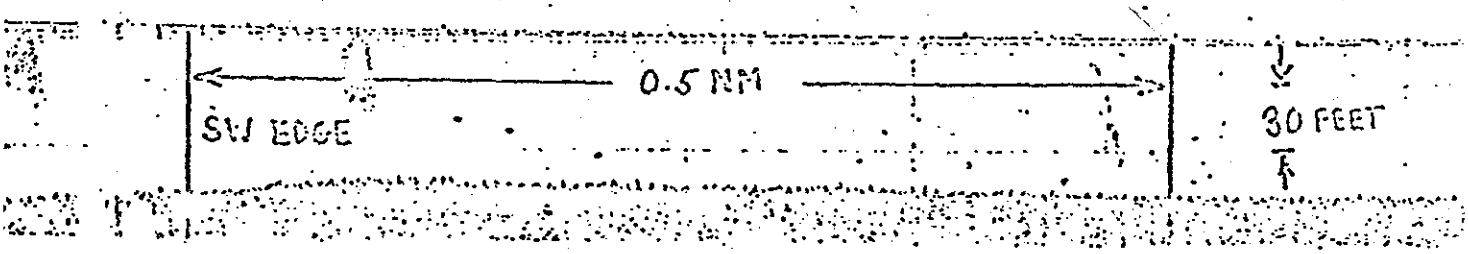


Fig. 10-2. Near subbottom profile of a SW-NE traverse bisecting the designated dumping zone made with the Raytheon CESP system (40° beam, 3.5 KH_z). This section is the same as that shown in Fig. 9-3. The spoil can be seen on the slope of low ridge with a SE strike.

nerously provided test runs over the study area using their recently developed CESP system. This system uses a wide bandwidth long duration signal which is stored as a reference replica and correlated with the returning echo from the sub-bottom layers.

Figures 10-1 and 10-2 show photographically reduced records obtained using a 1KH_z narrow beam transducer and 3.5 KH_z wide beam transducer. These sections duplicate the bottom profiles shown in Figs. 9-2 and 9-3. Although the trace of high waves obscured these records somewhat, they were useful in determining the exact position of the spoil on the slope of a ridge which runs through the dumping area. Although this system has a theoretical resolution of about 2 feet, the thinnest layers that could be seen in the test records were between 3 and 4 feet thick. This resolution would not be sufficient for mapping spoil which has spread in very thin layers. Cores would be necessary in such an area.

It was concluded that near sub-bottom profiling could be a valuable addition to the present techniques for mapping sediment thickness.

Surface distribution of spoil

The surface distribution of spoil was mapped from bottom samples collected during the summers of 1969 and 1970.

In August, 1969 41 short cores were collected by University of Rhode Island personnel. Visual descriptions of the cores and data from mechanical and chemical analyses are given in Tables 1 and 2. The sampling array is shown in Fig. 11. Symbols on the map identify the sample locations that yielded visually recognizable spoil materials. These were found mainly within the designated disposal area.

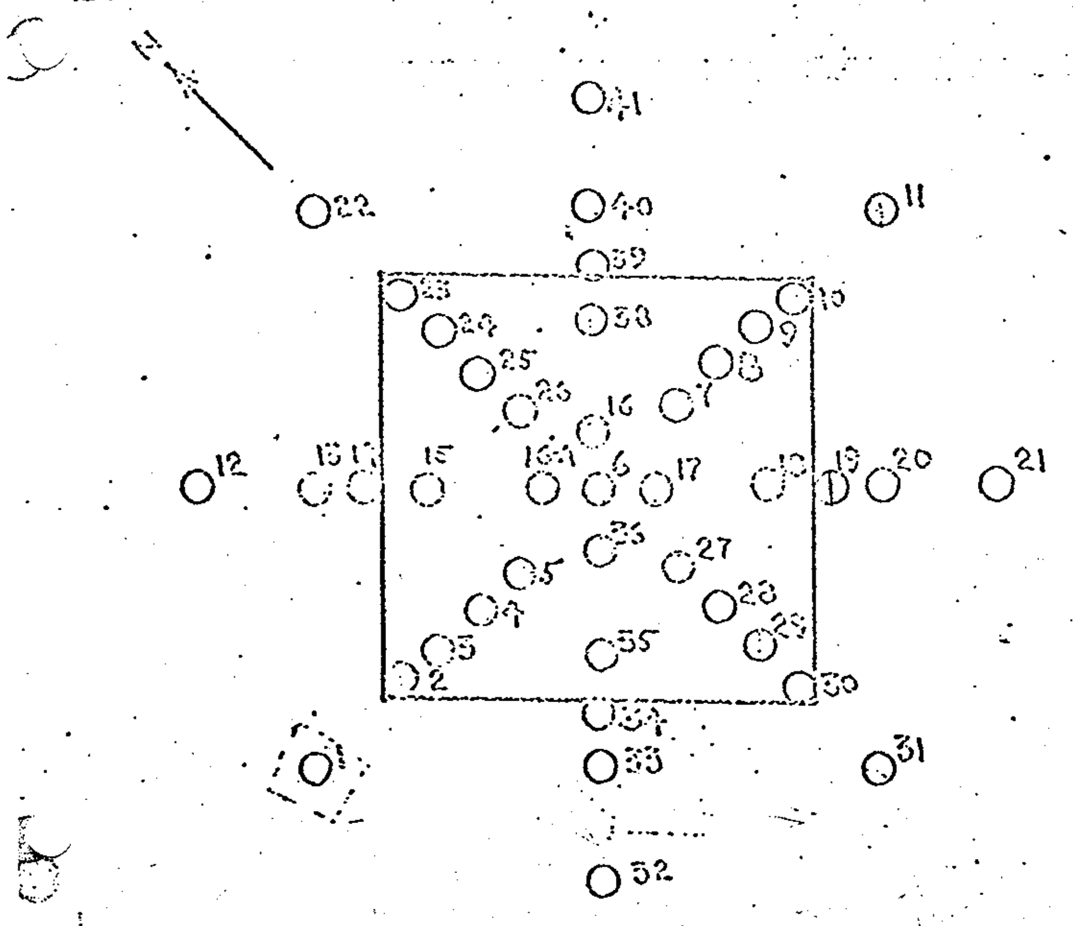


Fig. 11 Core samples taken from the dump site and its vicinity during August, 1969.

- Samples with characteristics of spoil
- Samples with spoil overlying original sediments
- Samples of undisturbed original sediments

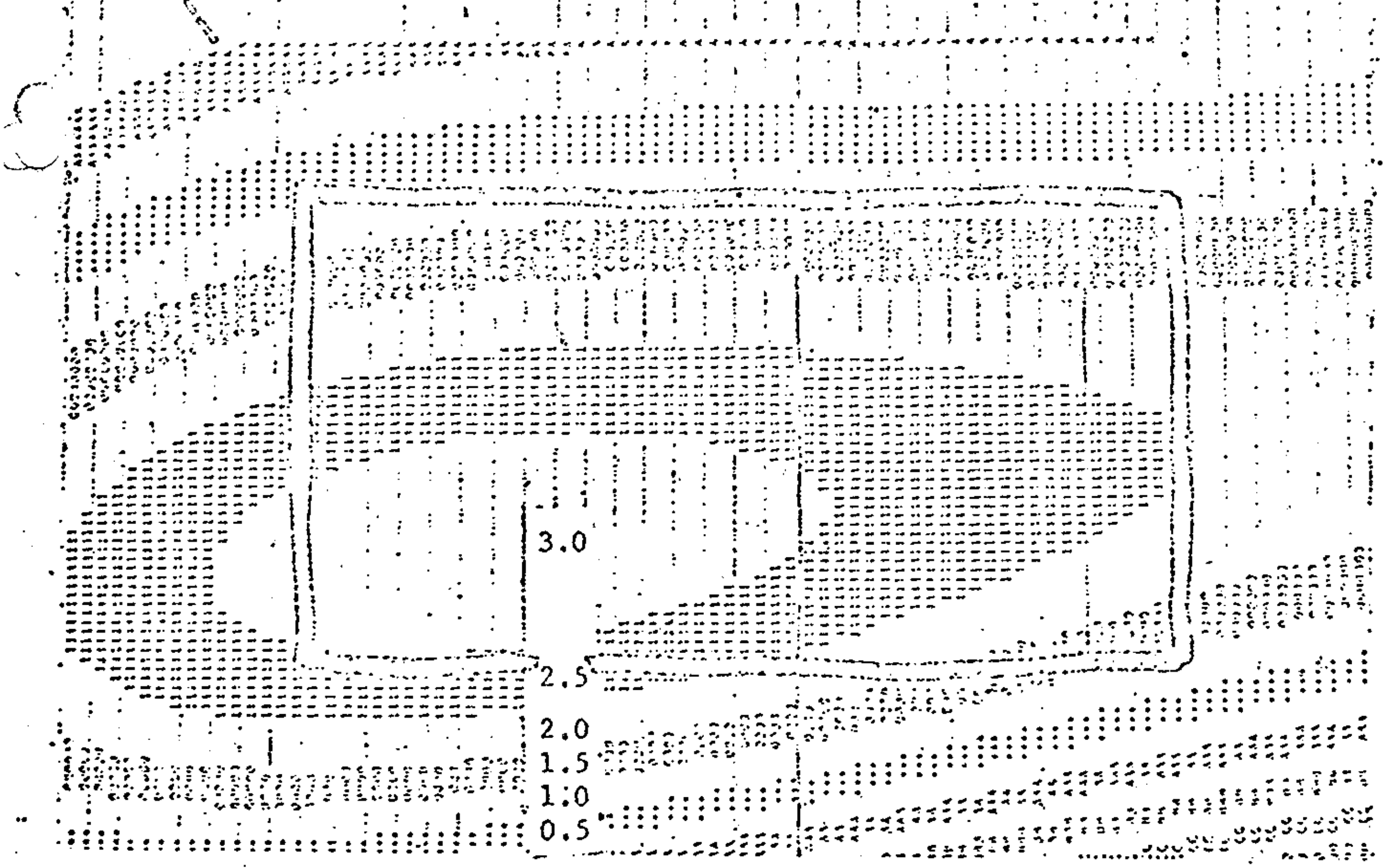
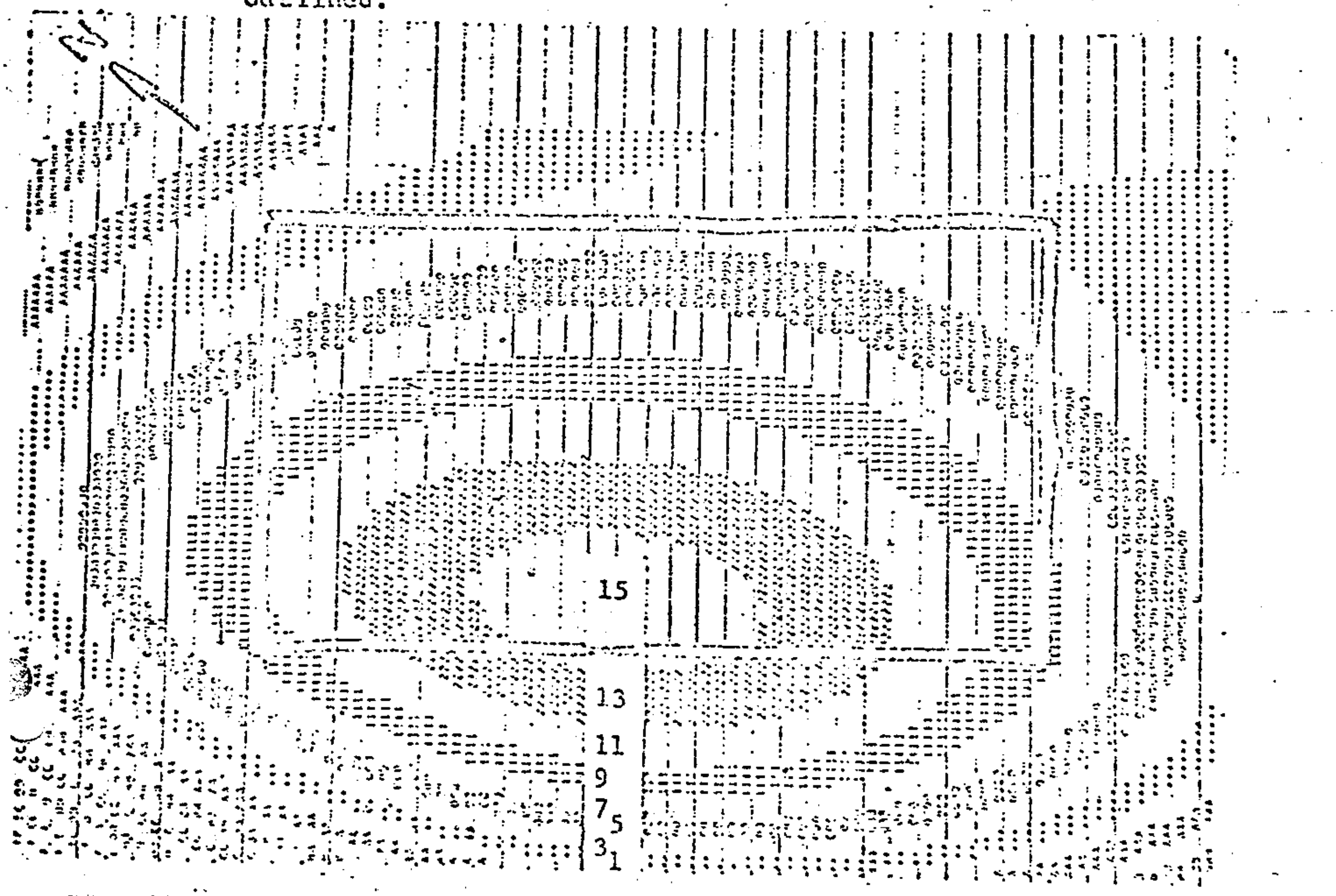


Fig. 12-1 Percent carbon in sediments August, 1969. Third-degree trend surface fit. Contour interval 0.5% Designated dumping area is outlined.



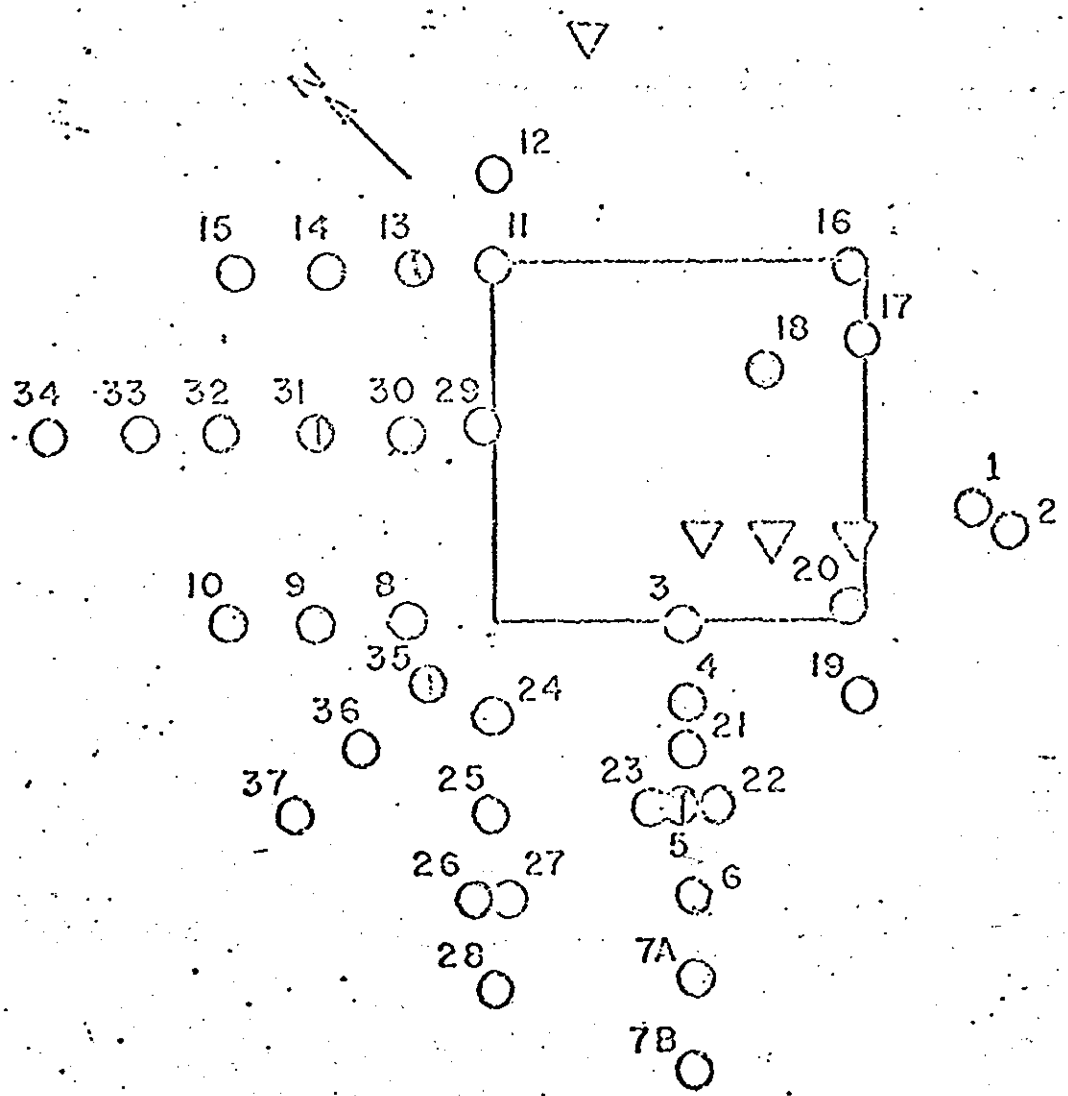


Fig. 13 Grab samples from the dump site and its vicinity taken July-September,1970. Sample numbers are shown in figure 2.

○ Samples with characteristics of spoil

⦶ Samples with spoil overlying or mixed with original sediments

○ Samples of undisturbed original sediments

Although the spoil was made up of a variety of materials, nearly spoil samples contained higher percentages of fine particles and organic matter than did the sandy sediments in the disposal area. A computer technique, described in detail in Appendix I, was used to contour the percent silt-clay and the percent carbon from these samples. Least square surfaces were fitted to the data points. These became increasingly complex as the degree of the trend surface equations was increased from 1 to 6. Tables 3 and 4 give the equations and error measures for these surfaces. The higher degree surfaces were not useful in this application because they fit each variation within the spoil deposit, obscuring the general pattern of spoil distribution. The third degree surfaces (Figs. 12-1 and 12-2) illustrate this pattern more clearly. Spoil sediments with a relatively high percent of silt/clay and carbon are found within the dumping area and spreading outside to the SW in the case of silt/clay and W in the case of carbon.

During June-October, 1970 a series of Petersen grab samples were taken from the R/V La Nina. Most of the samples were taken outside the designated dumping area (Fig. 13). Considerable small scale heterogeneity in sediment types was encountered. Inside the dumping area the spoil materials varied, while outside at patches of spoil were found on the original sandy bottom. The perimeter of the area affected by the presence of gross quantities of spoil included 3 to 4 square miles. Although there was much clean bottom within this perimeter, was also a probability of finding dredge spoil there.

The visual descriptions of these grabs are given in Table 5. The characteristic sediment type in the center of dumping activity was dense gray sand/silt/clay. This sediment contrasted strongly with the black polluted materials described by Saila, Polgar and Rogers (1968) indicated the progress of the dredging operation from Providence arbor to upper Narragansett Bay. Samples taken in the late summer of 970 showed a distinct grey silt/clay layer 1-2 cm. thick mantling oth the spoil "pile" and the original bottom S and W of the disposal rea. A very large number of samples would be required to complete a ap of the spoil deposit since the basic sedimentary units are patches not ore than a few hundred feet in diameter.

iver examination of the dump site

In October, 1970 SCUBA divers made direct observations of topographic eatures, animal life, and sediment variability in the area of active umping. It was felt that these were necessary to properly interpret ymetric records and grab samples from the area. An attempt to make uch observations by submarine photography during 1968 had failed, robably because of turbidity caused by contact of the equipment with the ottom.

The dive was made during calm weather at a time when current velocity as barely perceptable at the surface. The surface water had the expected igh clarity of Rhode Island Sound water in autumn. The water a few feet from the bottom contained some suspended material but still appeared less turbid than Narragansett Bay water at any time of the year. Enough green light penetrated to enable the divers to see the general topography.

The bottom was covered with a smooth layer of homogeneous grey silt. Contact with this sediment generated dense clouds several feet high. The lt was soft and incohesive enough to allow a hand to be passed through it without appreciable resistance. More consolidated sediment with coarse sand in it was detected beneath this layer. A short core was taken which indicated that the surface layer was about 2 cm thick. Lumps of clay, marsh peat, and clinker ash 10-20 cm high protruded from the smooth bottom. The only "rubbish" seen was a shoe sole. Most of the bottom seemed horizontal to the divers except for one slope of about 5°. The extent of this slope was not detectable.

A single fish was seen, probably a sculpin (*Myoxocephalus* sps.) Adults of two species of crabs (*Cancer irroratus* and *Cancer borealis*) were collected and an American lobster (*Homarus americanus*) was seen on the sediment surface. A small unidentified crustacean was observed leaving a 3 mm diameter hole and swimming across the surface. The bottom was marked by distinctive straight trails made by lobsters and crabs.

The bottom showed little evidence of wave or current activity. Ripple marks were seen in only one area. These had a wavelength of about 10 cm and were of very low amplitude. They seemed to be made visible by sorting of light and dark colored sediment particles.

These observations were extremely valuable in visualizing the active dumping area. In the future divers should return to this area to assess the effects of winter storm waves on the surface sediments. Dives should also be made on the edges of the dump site where animal colonization has begun.

Conclusions

Within the limits of the precision of the bathymetric surveys the volume of spoil on the disposal area was the same as that reported dumped. No large scale loss had taken place during or after the dumping operation. The presence of a layer of incohesive silt/clay on the spoil surface during the summer indicated a non-erosive physical environment during that period.

Much of the polluted spoil from Providence Harbor which was deposited during the early part of the dredging project has been buried by less polluted sediment from upper Narragansett Bay. Polluted spoil was left unburied outside the dumping area to the NW and inside the dumping area in the N and E corners. This spoil was found as much as a mile outside the dumping area on the route from Narragansett Bay to the dump site.

The combined effect of dumping pattern, sediment properties, and hydrographic variables has produced a low cone of spoil approximately a mile in diameter. This indicated that the one square mile assigned dumping area was of adequate size. Spoil extended outside the designated area to the W and S only because the center of dumping has been close to the W corner.

SEDIMENTS OF THE DREDGING AND DISPOSAL AREAS

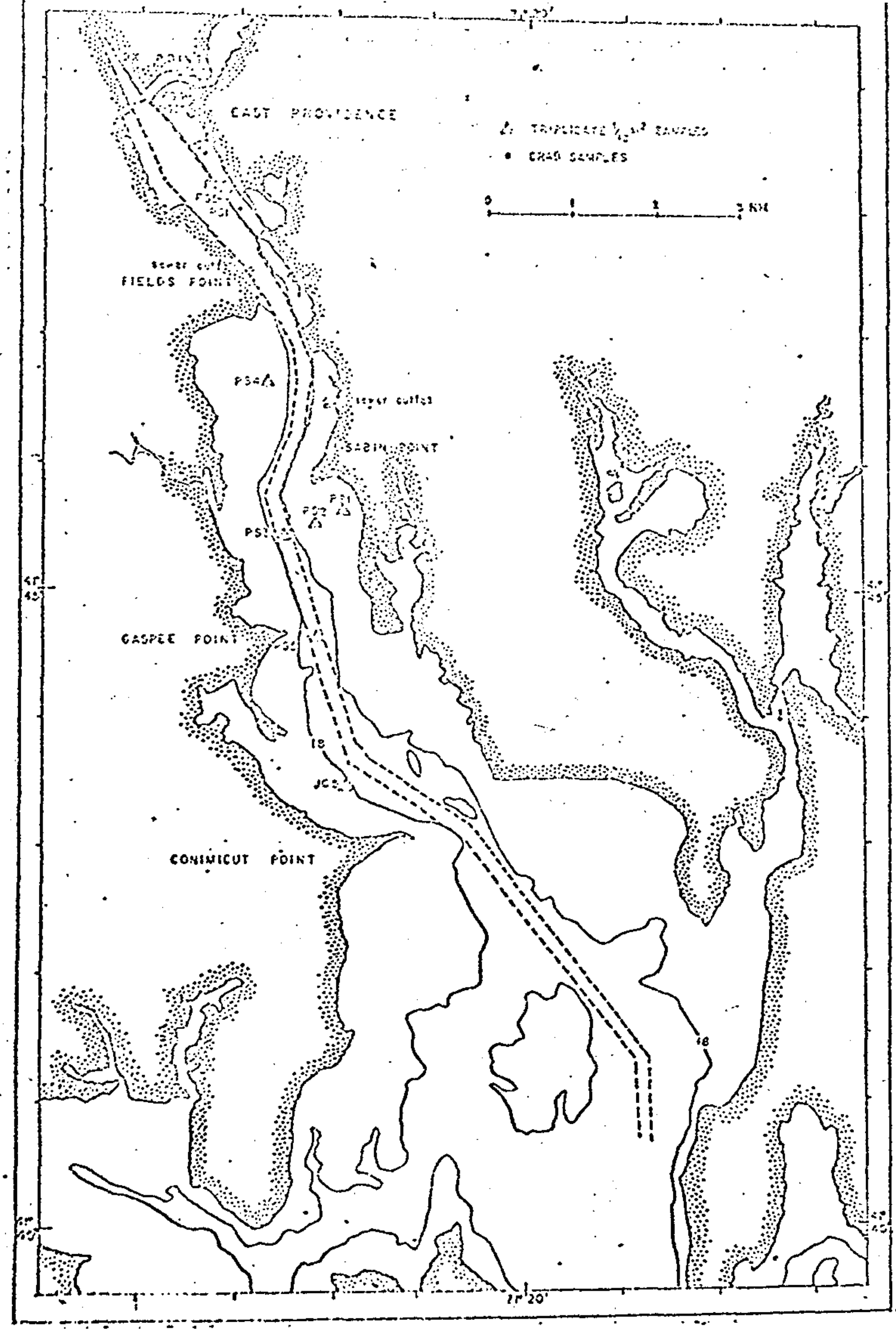
The sediments encountered in this study are described to provide a basis for: 1) distinguishing spoil materials from natural sediments; 2) predicting the stability of the spoil under the hydrographic conditions of Rhode Island Sound; and 3) studying animal-sediment relationships.

Selected sediments were analyzed using a combination hydrometer and dry sieve method (ASTM, 1968). Material remaining in suspension in the hydrometer settling tube after 60 minutes was reported as clay. Sieves at a 1/2 ϕ interval were used. Percent frequency and cumulative percent frequency of the weight of size fractions were graphed. Median grain size and the geometric sorting coefficient, So, were derived from these graphs. So, a measure of spread around the mean, varies from 1.18 - 1.25 for well sorted beach sands to 4.76 for unsorted glacial till (Krumbein and Sloss, 1963). The percent loss on combustion was used as an indication of the amount of organic matter in the sediments. Three subsamples were dried at 80° C and combusted for three hours at 575° C. The weight losses of the subsamples in all cases were within 1% of each other.

Sediments of the dredged area:

The dredge spoil included sediments of types presently being deposited in Providence Harbor, the Providence River, and upper Narragansett Bay as well as those which were deposited under various sedimentary regimes following the last ice advance.

Providence Harbor is an area of active sedimentation. Between 1945 and 1955, 1,100,000 cubic yards were removed from the harbor to maintain design depth (U.S. Army Corps of Engineers, 1959). This was 46% of the total amount dredged from the ship channel in that interval. This sediment



g. 14. Location map showing the following areas mentioned in the text:
1) Providence Harbor: north of Fields Point
2) Providence River: between Fields Point and Conimicut Point
3) Upper Narragansett Bay: south of Conimicut Point

could have had a variety of sources.

Clays entering in river water would flocculate immediately at the reported salinities of 10-27 o/oo at the surface and 27-30 o/oo at the bottom (Hicks, 1959). These sediments, however, show a paucity of clay size particles. Suspensions in both aquaria and settling tubes became clear in about 90 minutes. Microscopic examination of the sand size particles from shallow samples (map, Fig. 14) revealed that most were worm fecal pellets, 0.25 mm by 0.12 mm. These yielded very fine particles when disaggregated with hydrogen peroxide. The worms that mat the bottom with densities of $100{,}000/M^2$ ingest the fine surface sediments and produce sand size particles of low density. It was not possible to determine the depth to which these pellets remained aggregated, but Moore (1955) states that they may remain complete for up to 100 years.

The U.S. Army Engineer Waterways Experiment Station modeled sediment transport in the Providence River (U.S. Army Corps of Engineers, 1959). Easily transported materials initially distributed throughout the channel accumulated in the Harbor indicating that fine materials from down stream are probably an important source of sediments in the Harbor. Sources of particles with high organic content include the highly polluted Blackstone River entering at the head of the estuary, the Pawtuxet River entering opposite Sabin Point, and the sewage treatment plants at Fields Point and in East Providence.

The harbor sediments examined had a loss on combustion of 10-12% and were anaerobic below the upper millimeter. Silica frustules of diatoms and much plant detritus were found preserved in these sediments. Petroleum was present in these samples but did not effect the sediment texture. The highest values for hexane extractable material given by Saila, Polgar, and Rogers (1968) of around 0.8% of dry weight were presumably from harbor sediments. Hexane soluble materials include fats and oils from sewage and natural sources as well as hydrocarbons from oil spills.

The surface sediments from the channel of the Providence River between the harbor and upper Narragansett Bay have been generally classified as organic silt (Hard, 1970). McMaster and Clarke (1956) reported that though the sediments are generally fine grained, the silt-clay fraction varied from 94% in shoaling areas to 3.3% in constricted areas where erosion predominated. A high proportion of wood, leaves, and seeds were characteristic of the sandy silts at stations PS 3 and PS 5 (map, Fig. 19). These contributed to the 4-6% loss on combustion of these samples. Surface sediments were characterized by the shells of a very abundant bivalve, *Mulinia lateralis*, while abundant oyster and scallop shells in the deeper sediment represented former populations which have been eliminated by pollution.

Stations at PS 1 and PS 2 in shallow water along the edges of the channel had very soft black sediments with 12% loss on combustion, much higher than that of the channel bottom sediments. Reduced current velocity and polluted surface water seemed to be responsible for this concentration. Some preliminary determinations of hydrocarbons in sediments from this area (Farrington, 1971) gave values of .05-.57% of dry weight. These hydrocarbons appeared to be "aged" petroleum, made up of cyclic saturated compounds.

The sediments of upper Narragansett Bay reflect a reduction in current velocity with increasing cross section. McMaster (1960) reported a clay content of 10-30% in this area. This was a high value for Narragansett Bay sediments. The silt content was 60-65% and the sand content was 10-25%. These sediments are well oxidized and are inhabited by a normal estuarine fauna.

The dredging operations frequently penetrated into layers of sediment deposited under different conditions than are found today. These included silts and sands deposited in the post glacial river valley previous to salt water intrusion. Beneath these were found laminated fine sands, silts, and clays deposited during the last glacial retreat.

Sediments in the dump site area:

McMaster (1960) showed the general pattern of sediments in Rhode Island Sound (Fig. 15). The bottom is generally sandy but becomes silty in a depositional area east of Point Judith. Lag deposits of gravel and cobbles mark the location of eroded glacial moraines.

The sediment at station 7-3 (map, Fig. 2; graph, Fig. 16) was a clean yellow sand representative of the original sediments on the dump site and to the north and east of it. Cores 40, 39, 23, 25 and 20 (Fig. 11) also sampled this type of sediment. All were 95-99% sand with a grain size mode at 0.25-0.10 mm and were very well sorted. The loss on combustion for station 7-3 was only 1%. These sands contained fragments of bivalve shells and sand dollar skeletons. Quartz grains were subrounded and stained with iron oxide.

Large areas of this sand were covered by dense mats of the tubes of amphipod crustaceans. These mats had trapped suspended sediment and the fecal matter of the amphipods. The color of the sediment was olive brown. The grain size distribution (Station 14, Fig. 17) showed added fine particles. The loss on combustion was 3% for the tubes and 2% for the sediment.

Fine sediment, winnowed from shallow waters or transported from Narragansett Bay after storms, is presently being deposited east of Point Judith (McMaster, 1960). The sediment at station 9-2 (Fig. 18) was an extremely well sorted silt with a median grain size of 0.06 mm, no particles larger than 0.177 mm, and only 7% clay. Apparently wave and

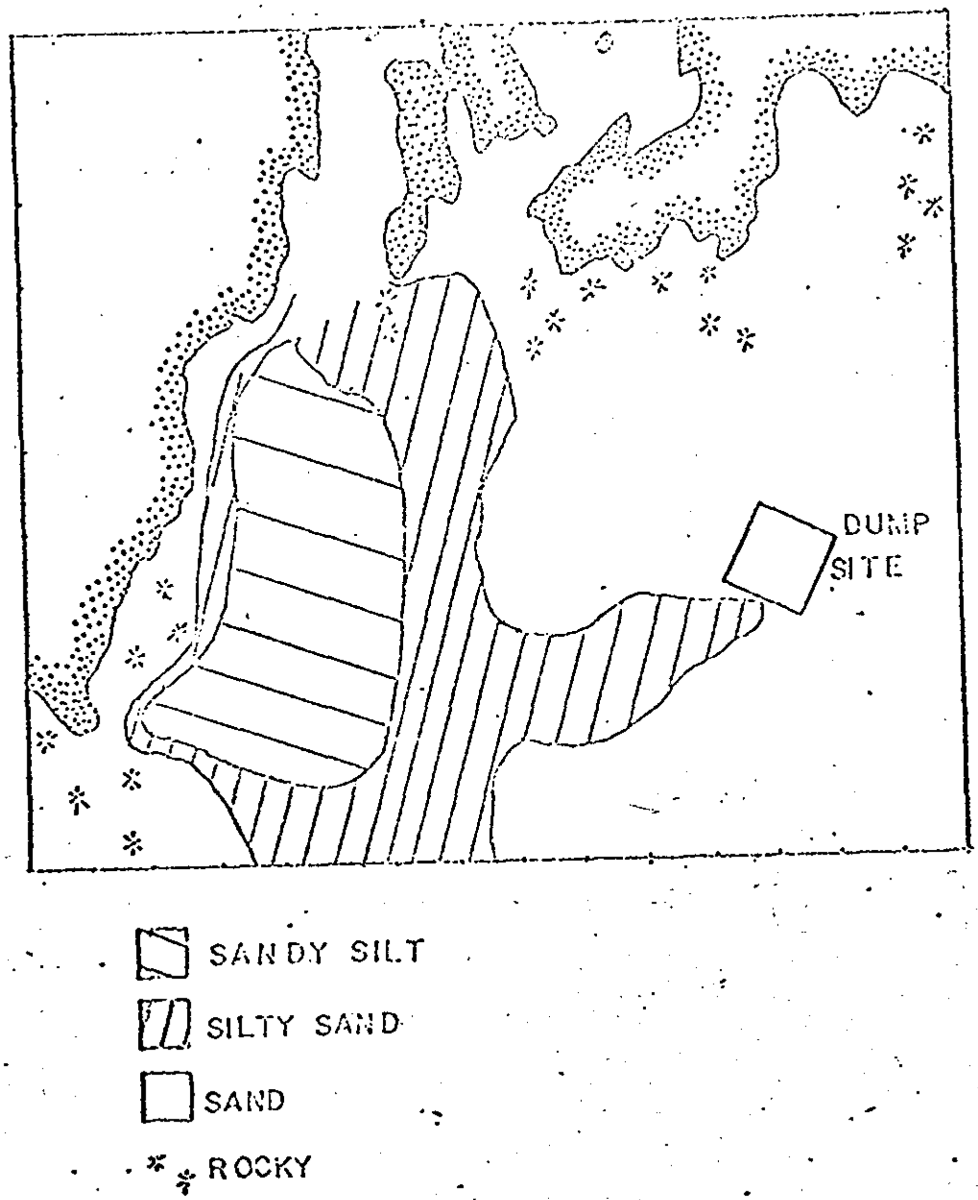


Fig. 15 General surface sediment distribution of Northwest Rhode Island Sound. (from McMaster, 1960)

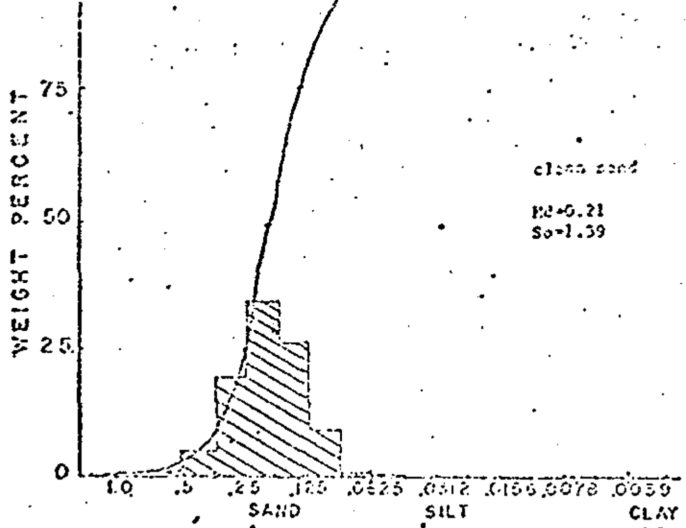


Fig. 16 Sta. 7-3

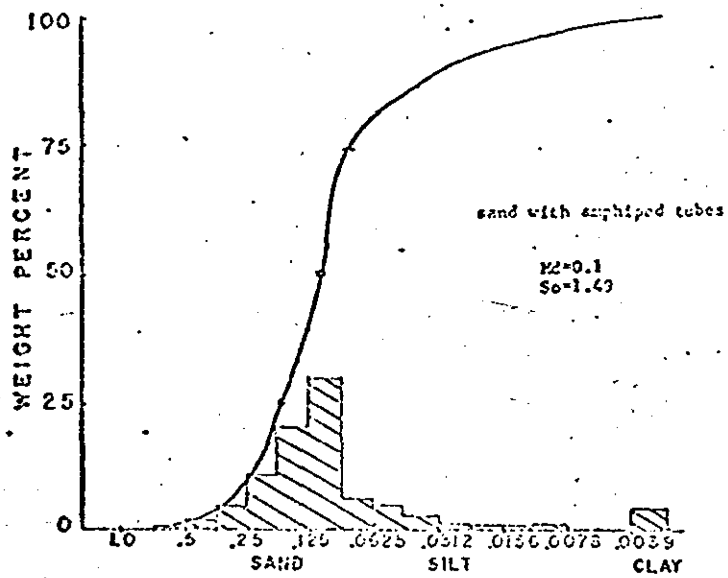


Fig. 17 Sta. 14-2

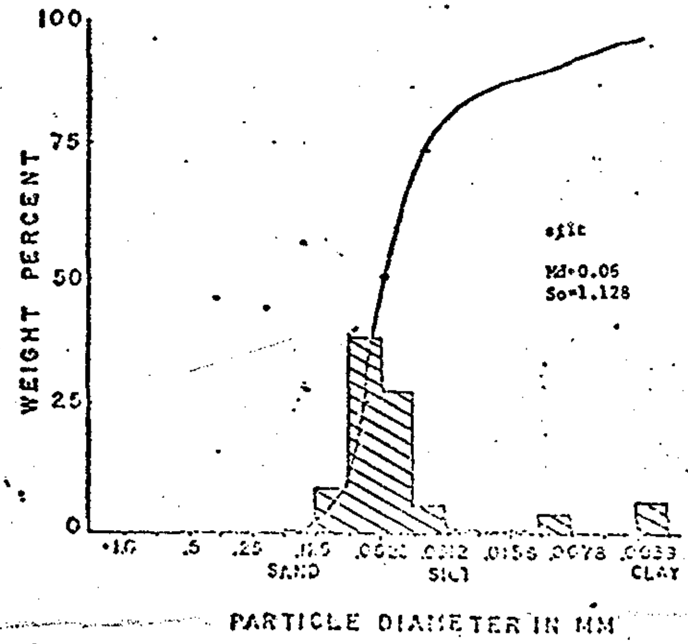


Fig. 18 Sta. 9-2

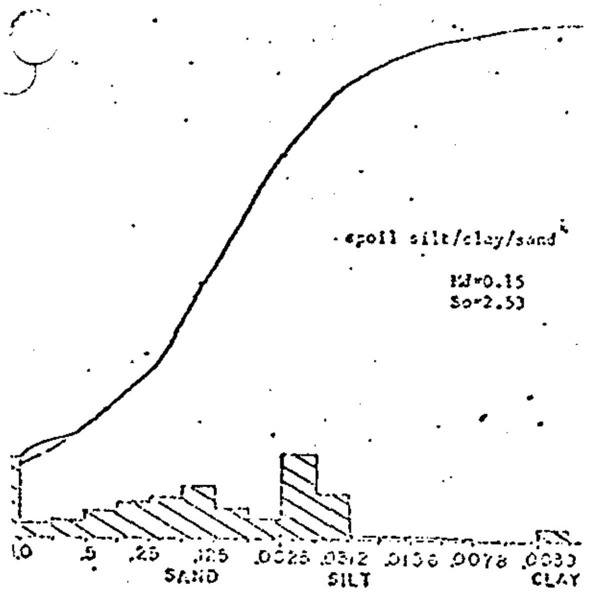
current energy is not competent to carry coarser sediments to this area, the clays remain in suspension and are deposited elsewhere. The loss on combustion was 4%.

Spoil sediments:

The sediments found on the dump site were very heterogeneous. Stations 8-1 and 8-3 yielded a coarse sand with shells. This sediment showed poor sorting and no grain size mode (Fig. 22). The presence of the shells of the soft shell clam (Mya arenaria), quohog (Mercenaria mercenaria), oyster (Crassostrea virginica), jingle shell (Anomia simplex), and common mussel (Mytilus edulis) indicate an estuarine origin. Strong currents in the area or origin probably concentrated shells from both rocky shore and soft bottom. Loss on combustion was 0.6%.

Samples at stations 11-3, 8-2, and 10-2 were made up of mixtures of black silt, light colored sandy clay, granules, and pebbles up to 2 inches in diameter (Figs. 19, 20, 21). These may have represented natural estuarine sediments or could have been "manufactured" during dredging and dumping. They were easily separable from the original sediments of the area on the basis of the presence of pebbles, clay and plant detritus and by poor sorting values. Loss on combustion varied from 2.7% to 3.8%.

The grain size distribution of a soft gray silt which was found mantling the active area of the dump site is shown in Fig. 23. The median grain size was in the silt range and clay made up of 17% of the total weight. Sizes over 1 mm were absent. It is believed that this material was formed during the dumping process. Silt suspended during the dumping of the spoil and from its impact with the bottom would have fallen more slowly than sand and pebbles, producing a graded bed. The core from which this sediment was taken had a sandy horizon 8 cm beneath the surface. A series



g. 19 Sta. 11-3

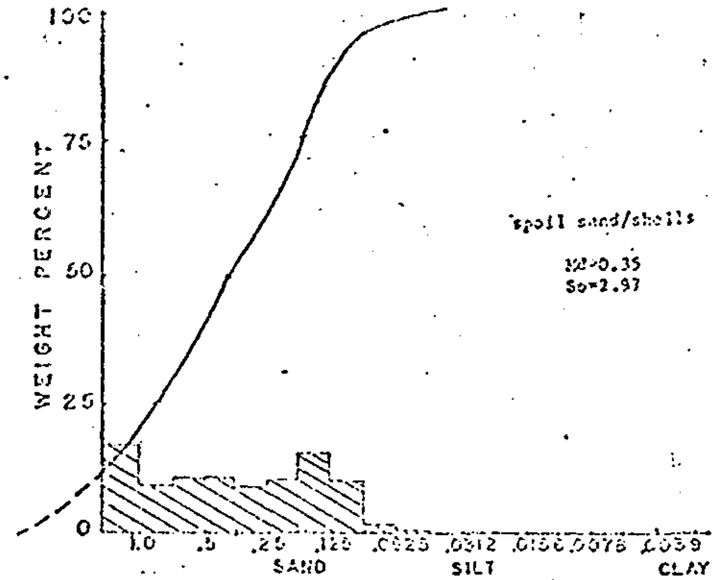
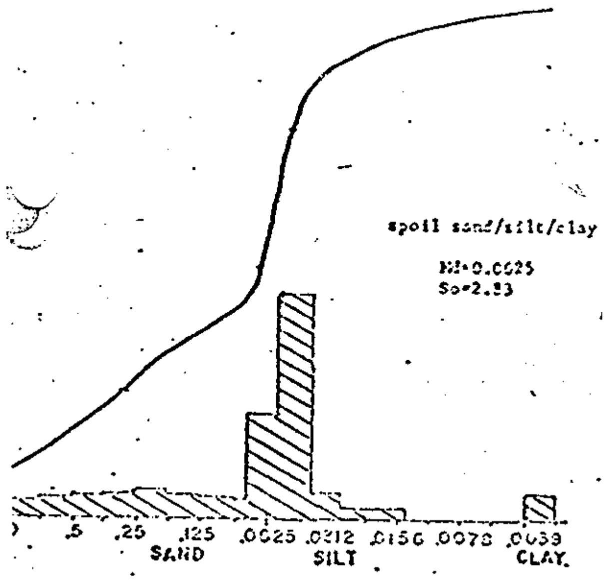


Fig. 22 Sta. 8-1



. 20 Sta. 8-2

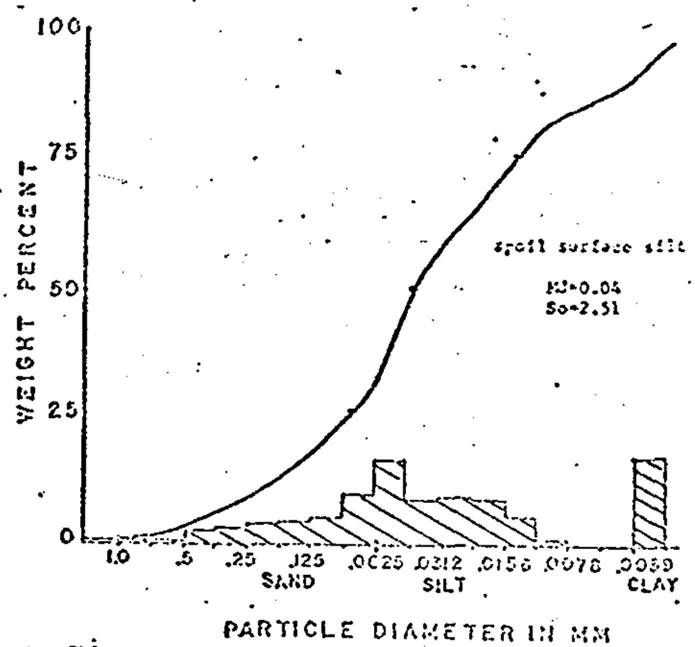
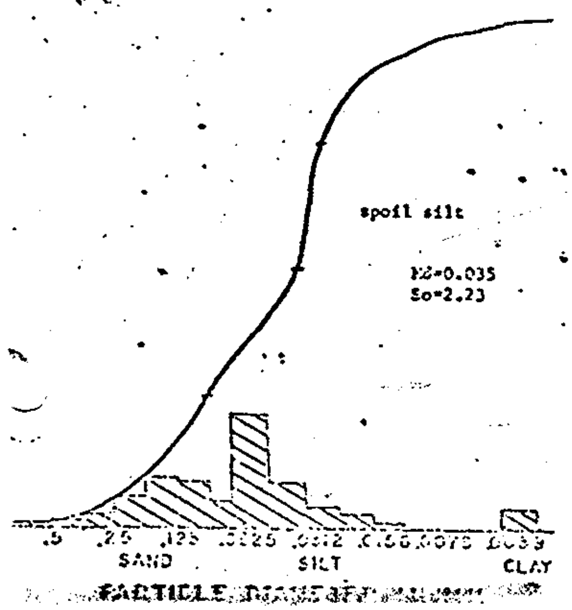


Fig. 23 Core sample from dump center



of shallow cores would indicate whether this stratigraphy is widespread.

Although much of the spoil had a smaller median grain size and a higher percent organic matter than the natural sediments in the dumping area, these were not always distinguishing characteristics. Poor sorting and the presence of the shells of estuarine mollusks were more reliable indicators. The presence of clay, pebbles, plant detritus, oil globules, and grey or black color also identified spoil.

No attempt was made to identify spoil which had been transported away from the dump site by waves and tides. This could be difficult because particles would have nearly the same grain size as those of the area to which they have been transported. Qualitative differences of the particles could be used to identify their source, however. Wood fragments were recovered SW of the dump site indicating transportation from the spoil dump. Petrography and shape analysis of sand grains could be used to identify transported sand. McMaster (1962) showed that the amphibole/opaque ratio of sands from the Providence River was 4:1, while the ratio in the area of the dump site was 1:4. The quartz grains in the offshore sands were more spherical and more rounded than those in the spoil.

If it is assumed that the well sorted sands of the dump site area are in equilibrium with the hydrographic regime at that location, it is possible to assess the relative stability of the various spoil sediment types. The thin layer of soft silt/clay mantling the spoil surface would probably be easily eroded. The denser mixed sediments underlying may be rather erosion resistant. It would appear that some silt will be lost from less dense mixed sediments until a protective sandy lag deposit developes. The depth of lag necessary to provide protection is conjectural, however the absence of ripple marks in this area suggests that a relatively shallow layer would be sufficient.

It would be of considerable interest to obtain data on the suspension of spoil sediments during storms and on the rate at which they settle afterward. This information is necessary to assess possible effects on fisheries.

The colonization of the spoil by populations of the tube building animals could slow the rate of erosion. Neumann et al. (1970) showed that sediment covered by an algal mat could withstant direct current velocities 2-5 times those which eroded unprotected sediment. Carriker (1967) cited several studied which showed the role of rooted aquatic grasses in stabilizing sediment.

Amplescid amphipods covered the sediment in parts of the dump area ...th dense mats of soft tubes. These may protect the sediment from erosion ...d act as traps for fine materials. Mills (1967a) found that ampelisca colonies on intertidal flats undergo periods of erosion during storms. No information is available, however, on the resistance of mats to storm waves or on the permanence of colonies in deep water.

CHARACTERISTICS OF THE PHYSICAL ENVIRONMENT

Introduction

Examination of the current and wave regimes of the physical environment in the dumpsite area provides some useful conclusions regarding the fate of dumped sediments.

Spread of sediments from the designated area can take place immediately after the dump, when a considerable amount of sediment may stay in suspension for the order of hours (Saila, Polgar and Rogers, 1968). In this case, the currents prevailing at the time, the setting velocities and the sea-state will determine the range and direction of the dispersion. Settled sediment may also be transported out of the area in time. Although known bottom velocities in Rhode Island Sound (see for example Shonting, 1969) can act only occasionally to re-suspend settled sediments, wave action may frequently accomplish this, and consequently, the suspended matter may be transported away from the dumpsite by the prevailing currents. The range and direction of spread will once more depend on the factors mentioned above, while the amount of matter going into suspension in the presence of wavesand currents will be a function of sediment surface stability, average wave height and period, water depth and current speed. Finally, transport out of the dumpsite area may possibly be effected by rolling and saltating sediment particles under the action of waves and currents.

In the following discussion, some particulars of the transport mechanisms will be examined in order to evaluate the extent of spread which may be expected from the dumpsite area.

Current systems in Rhode Island Sound

To provide a framework for the results of field current measurements at the dumpsite, two recent studies on the Rhode Island Sound circulation will be reviewed here. The non-tidal circulation in Rhode Island Sound was investigated by Cook (1966). Shonting (1969) conducted a detailed 13-day study of currents, recorded by a square kilometer array of self-recording current meters, in the summer of 1967. The study area of this latter work was located approximately 6 n.m. from the dumpsite, bearing 150° (magnetic). The water depth was approximately 115 feet.

Shonting's (1969) investigation revealed that upper layer motion may be characterized as a westward-migrating drift in long meanders. The bottom motions were described as anticyclonic (clockwise) swirls with small net displacements (drifts). These characteristics indicate that tidally driven inertial flows combined with the tidal motions dominate the current regime. The mean speeds (obtained from arithmetic averages) in upper layer did not exceed 0.5 knots for the period of observation, while similar means computed for the bottom layer resulted in values not greater than 0.3 knots. The unusually high mean bottom speed values are attributable to the application of arithmetic averages to the data. It is more meaningful to compute the mean velocity by vector averaging, which in this case yielded smaller mean speeds, along with their respective directions. The mean velocity can be interpreted as the non-tidal component of motion. In effect, the mean speed and direction, obtained by the vector averages of velocities over several tidal cycles, will indicate the resultant net displacement of watermasses and suspended particles over the time interval included in the average. The oscillatory motion of the tide is eliminated by the averaging process, hence the mean velocity thus obtained approximates the non-tidal circulation component. The greater the time interval used, the more accurate is the net displacement estimate. If the flow patterns are fairly regular and repeat over two tidal cycles (appx. daily), then daily averages may be used to investigate the variation of net displacement with time. Shonting (1969) reported a consistently WSW net motion in the upper layer, but the bottom flow displayed small and random net transfer components.

The observed instantaneous variability in current vectors in both layers was assessed, and as a consequence, the presence of eddies was deduced having scales of less than a kilometer. The current fluctuations indicated that the upper layer contained approximately 5 times more turbulent energy than the lower layer. However, the same analysis also indicated a strong local increase in turbulence close to the bottom, where the mean flow interacts with bottom frictional elements.

In summary, the major findings of Shonting's (1969) study were:

1) the semidiurnal tide controls variations in current velocity in both layers,

2) the tidal components appear to control the bottom motion more directly, resulting in smaller net displacements,

3) the larger net displacements in the upper layer appear to result from tidally induced, secondary inertial flow,

4) abrupt and prolonged changes, characterized by more unstable oscillations, may be the result of large-scale perturbations which cause reduced mean motion, allowing ambient tidal forces to appear amplified,

5) the turbulent intensities increase close to the bottom.

Cook (1966) used drift bottles and seabed drifters to investigate the non-tidal component of circulation in Rhode Island Sound over prolonged periods of time. Due to the method, there is a large degree of uncertainty both in the direction and range of displacements. The findings of the drift studies are summarized seasonally in the table below:

SEASON	SURFACE DRIFT	BOTTOM DRIFT
Spring	N and E	NW
Summer	N	NW
Autumn	S	N
Winter	S	N
SPEED RANGE:	1.1 to 7.6 n.m./day	0.05 to 1.8 n.m./day

These results are generalized to the whole Rhode Island Sound region, and do not detail significant local variations. Within the report, a ore extensive discussion of non-tidal patterns ensues, and Shonting's (1969) study is in closer agreement with non-tidal measurements than it appears from the general results above.

It must be noted that the majority of bottles and drifters were not ecovered. Although some of these were found by vessels, they were mostly ecovered at the shore. A large number of shore recoveries were interpreted o mean northerly displacements, while no shore returns were assumed to ndicate southerly transport.

Cook (1966) notes (significantly) that in western Rhode Island Sound ne surface and bottom water showed net westward drifts in July, which is good agreement with Shonting's (1969) results, even if the general pattern n-tidal circulation is north-westerly on the bottom for the greater ... of Rhode Island Sound.

Based on the return data, there is evidence for the intermittent pearance of a large-scale cyclonic (counter-clockwise) eddy in the region. e eddy is thought to encompass nearly all of northern Rhode Island Sound. e dumpsite location is near the center of this transient eddy system. is reasonable to expect that because of the location, the eddy would tribute little to the flow energy at the dumpsite even if the non-tidal tern were considerably altered by it on the bottom from time-to-time.

Boat operators have consistently noted a strong SW surface current Rhode Island Sound at the time of the incoming tide. This may well be ected in the direction of bottom motions. Although the response of the om layer to surface current changes may be sluggish, the adjustment of flow will take place if conditions remain sufficiently uniform for ngth of time.

These studies, then, seem to indicate that the larger velocities may [illegible]W to SW on the bottom in the summer months. The net bottom transport ay be randomly directed, with a speed of the order of 0.10 knot or less, esulting in a possible maximum daily net displacement of approximately .4 nautical miles.

The flow patterns are probably dominated by the semidiurnal tidal omponent. It is not reasonable to expect simple anticyclonic rotation of elocity vectors in the dumpsite area however, since it is located in a egion which comes directly under the influence of currents from such tended water bodies as Narragansett Bay, Long Island Sound and Buzzard's ay. In other words, although the dumpsite may not be an energetic current ivironment, it is located in an interactive zone of several current ifluences. Shonting's (1969) measurements were made farther off-shore, [illegible]e the bottom water may not have been affected by the N-S tidal flow scillations of Narragansett Bay, while the stronger influence of the E-W dal flow associated with Long Island Sound probably did dominate the irrents at these stations.

Bottom net transport measured at the dumpsite can be reasonably pected to result from interactions of tidal flows. If the estuarine circu-tion of Narragansett Bay were to play a major role in modifying the bottom rculation, conservation of salt would require a consistently NW net ansport. It is unlikely that any salt-wedge return flow into Narragansett y will be an important part of net bottom transport here, although linity modifications of bay origin may be measurable at the site.

[illegible]ent measurements at the dumpsite

A Hydro-Products Model 502 recording current meter was used to gather ttom current data. The meter was placed near the west corner of the dump-te in early March, 1970. The current meter record obtained at this time (#1) was unsatisfactory for analytical processing. The second record (#2) s of good quality, and was obtained from near the south buoy of the dump-site between July 20 and July 24, 1970. The rotor of the current meter was approximately one foot off the bottom for this series of measurements.

The current meter was adjusted to operate at a rate of six sampling cycles per hour. Each cycle contained speed and direction points, taken alternately at four second intervals for three minutes of each cycle. After cursory examination of the records, it became apparent that good mean (net displacement) velocities could be obtained by vector-averaging 150 sampling cycle means which constituted the record for a 25 hour period. This time interval was chosen so that the average could be taken over two complete semidiurnal (dominating tidal component) periods, 12.4 hours each.

Figures 24-27 summarize the findings for the indicated periods. The ata for each 25 hour period are presented in three distribution diagrams. he upper left compass roses indicate the percentage of time the current as flowing in each of twelve compass sectors. An arrow marks the direction f net displacement for the period presented. The upper right diagrams show he speed probability density in intervals of 0.05 knots. The net displace-ent speed is marked on the speed distribution diagram. The lower compass ose indicates the distribution of speeds within each 30° compass sector. irections refer to degrees magnetic, and speeds are in knots.

Before any comparisons are made between these measurements and previous ork, it is well to point out that the record is relatively short, and may ot be typical of behavior over a long period of time. The measurements re taken when tidal heights in the area were unusually large.

In contrast to Shonting's (1969) findings, the bottom records for e four day period exhibited and retained definite, regular and repeating patterns. Over the four days the speed distribution shifted toward the low end of the spectrum (to lower velocities in general). The shift was also reflected in the consistent decrease of the net displacement speed. Peak velocities were recorded in the first day only, and were between 0.30 - 0.35 knot.

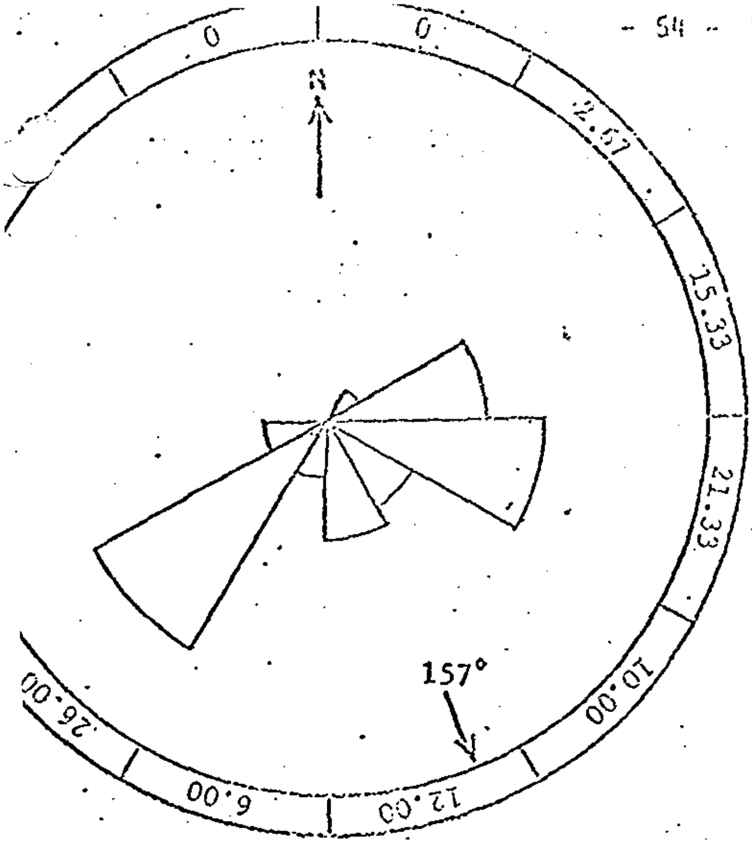
The direction histograms show a "figure 8" configuration, with two major lobes about 150° apart. This pattern seems stable over the four day period. It is to be noted that the current at no time (daily) flows in a 90° sector, i.e., no flow occurs in directions 270°-360° or 300°-030°. The speeds are also radically reduced in a direction 180° opposite to the empty quadrant.

The speed distribution within each 30° direction sector indicates that the largest velocities occur in the WSW sector in general, with subsidiary ima in the in ESE and ENE sectors. However, the direction histograms ow that WSW directions occur for a greater percentage of the time than ny other. This finding seems to substantiate that the strong surface SW currnets on the incoming tide observed by boat operators in the area lso dominate the bottom flow for the period of measurement.

The net transport velocities may be summarized in tabular form:

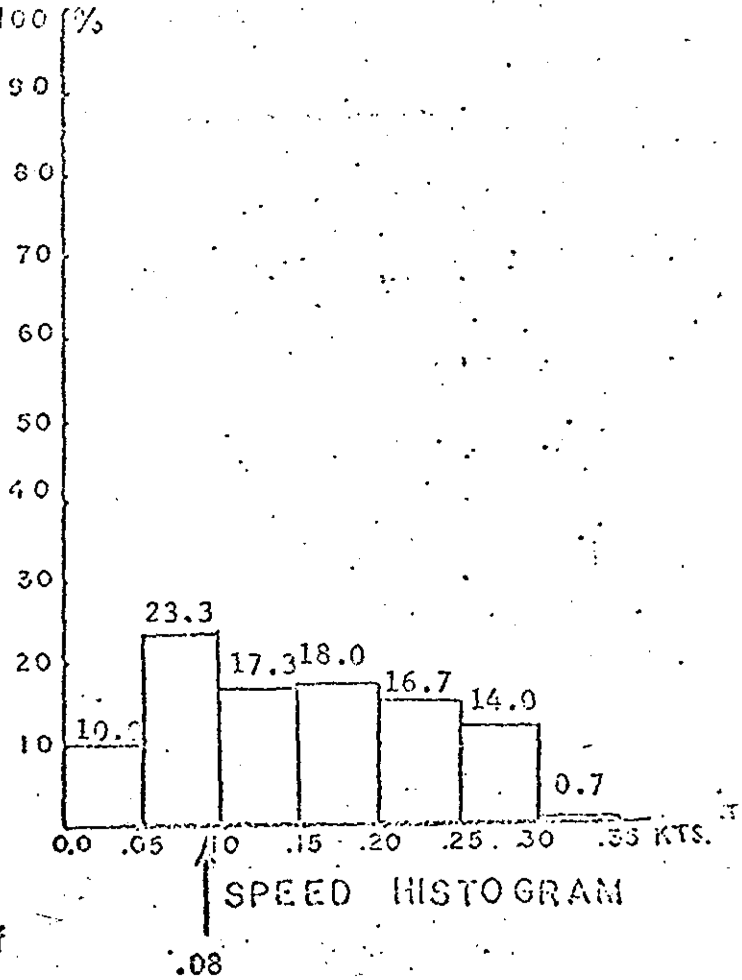
Date	Speed (kn)	Direction (°magnetic)
July 20-21	0.08	157°
July 21-22	0.08	186°
July 22-23	0.05	162°
July 23-24	0.03	156°

hile net transport direction changes from day-to-day do not follow a egular pattern, the speed decreases monotonically in time. Examination f the direction histograms indicate that the decrease in net transport ed may be closely correlated with the counter-clockwise rotation of the igure 8" flow pattern in time.



:CTION HISTOGRAM (radii = %)

indicates speed + direction of non-tidal drift



SPEED HISTOGRAM

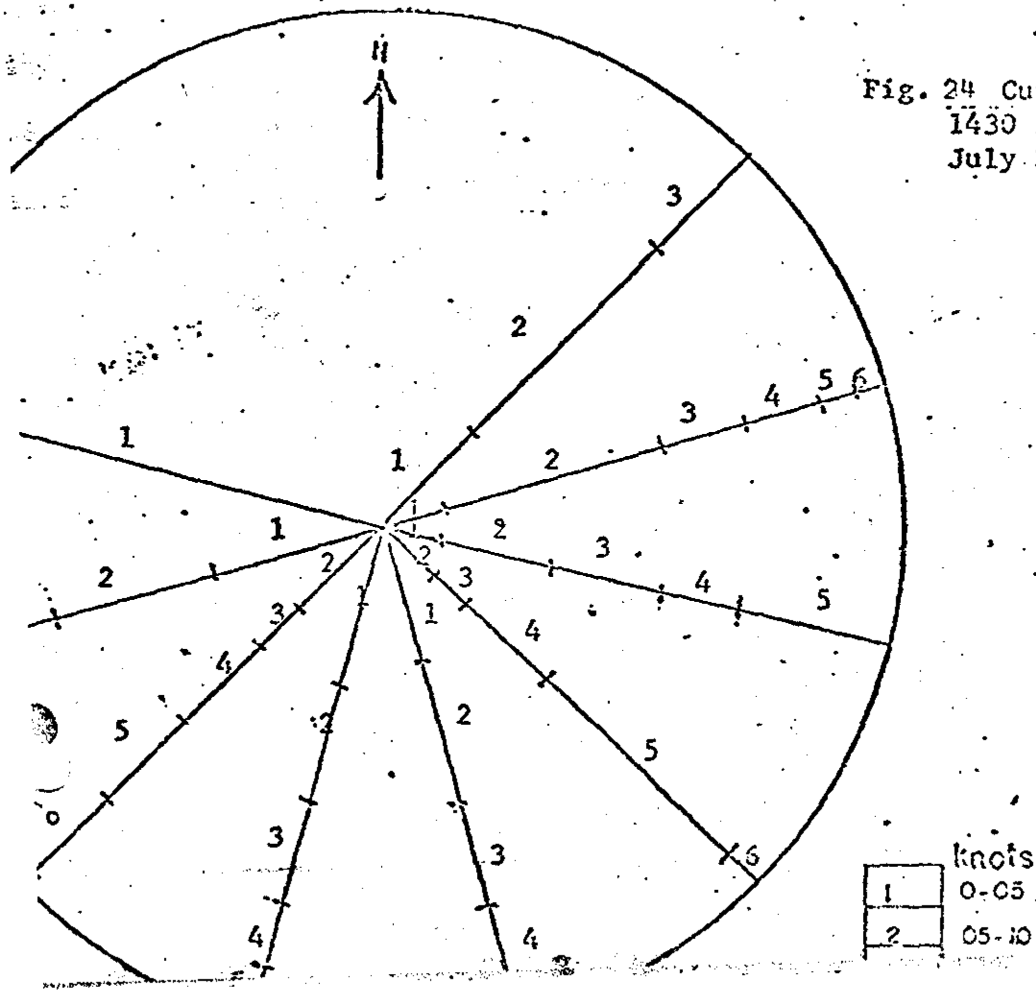
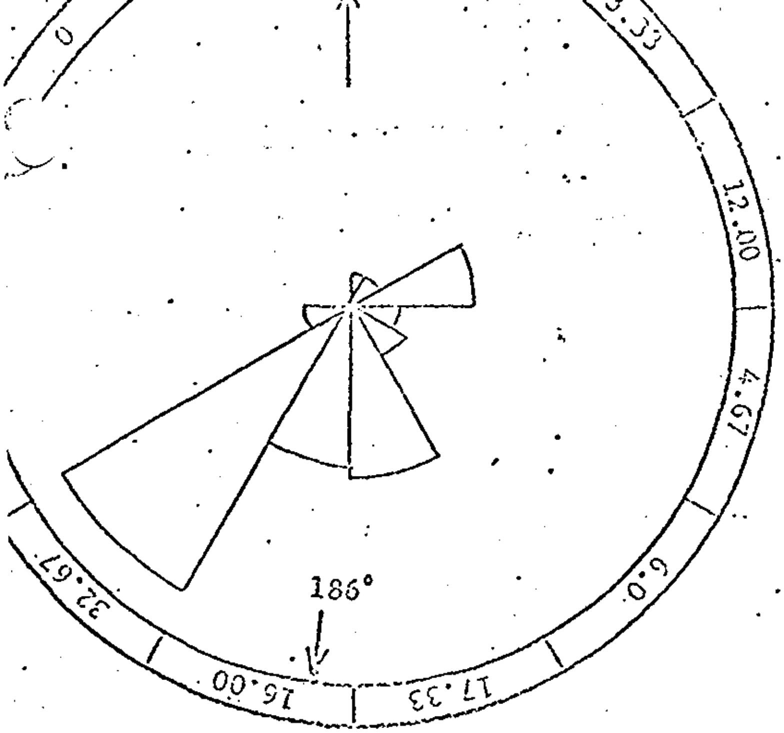
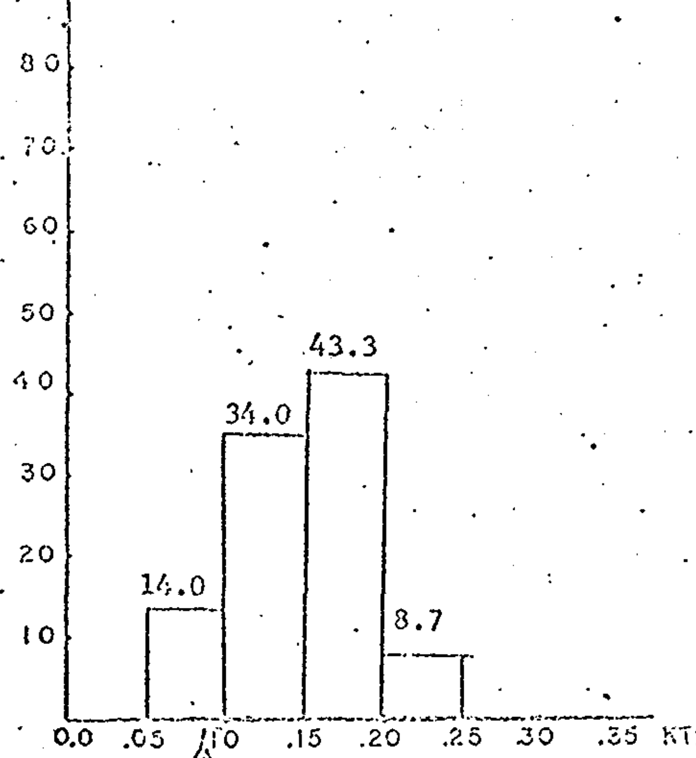


Fig. 24 Current meter records 1430 EST July 20-1520 EST July 21,1970





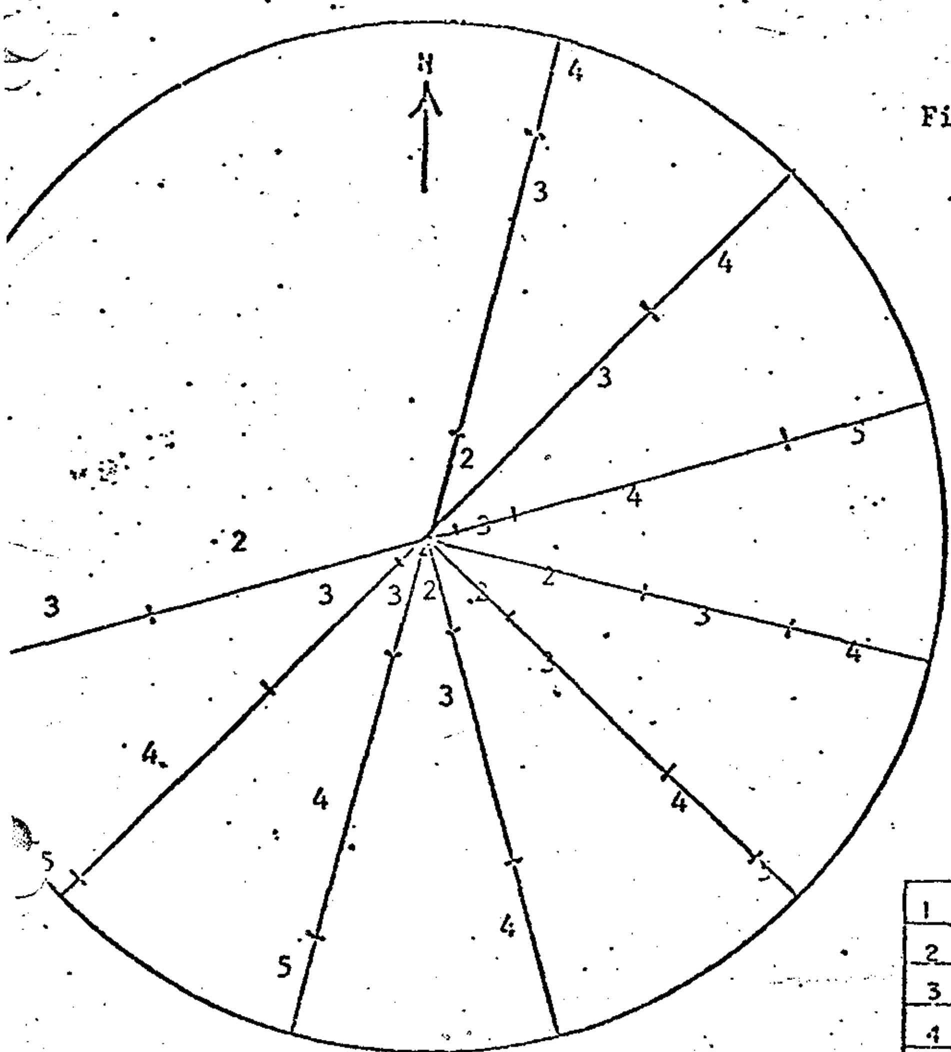
RECTION HISTOGRAM (radii = %)

SPEED HISTOGRAM

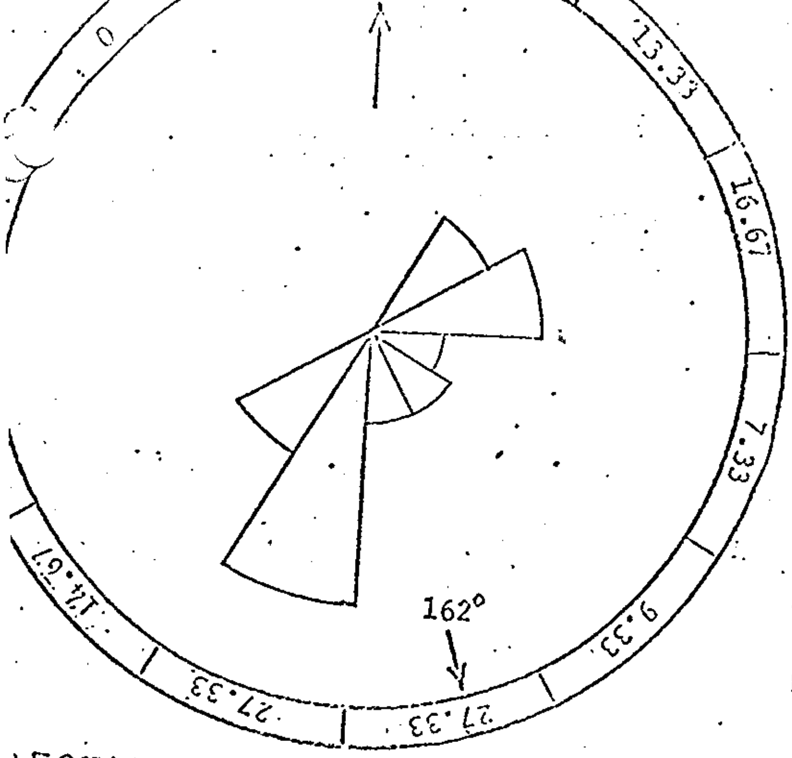
.08

⟶ indicates speed + direction of non-tidal drift

Fig. 25 Current meter records 1530 EST July 21-1620 EST July 22,1970

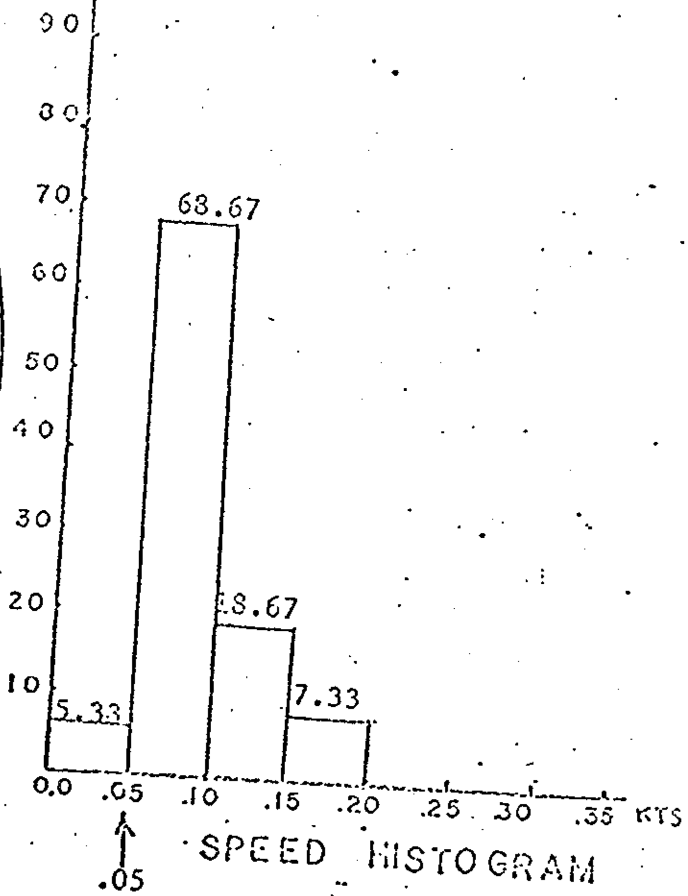


	Knots
1	0-05
2	05-10
3	10-15
4	15-20
5	20-25



ECTION HISTOGRAM (radii = %)

→ indicates speed + direction of non-tidal drift



SPEED HISTOGRAM

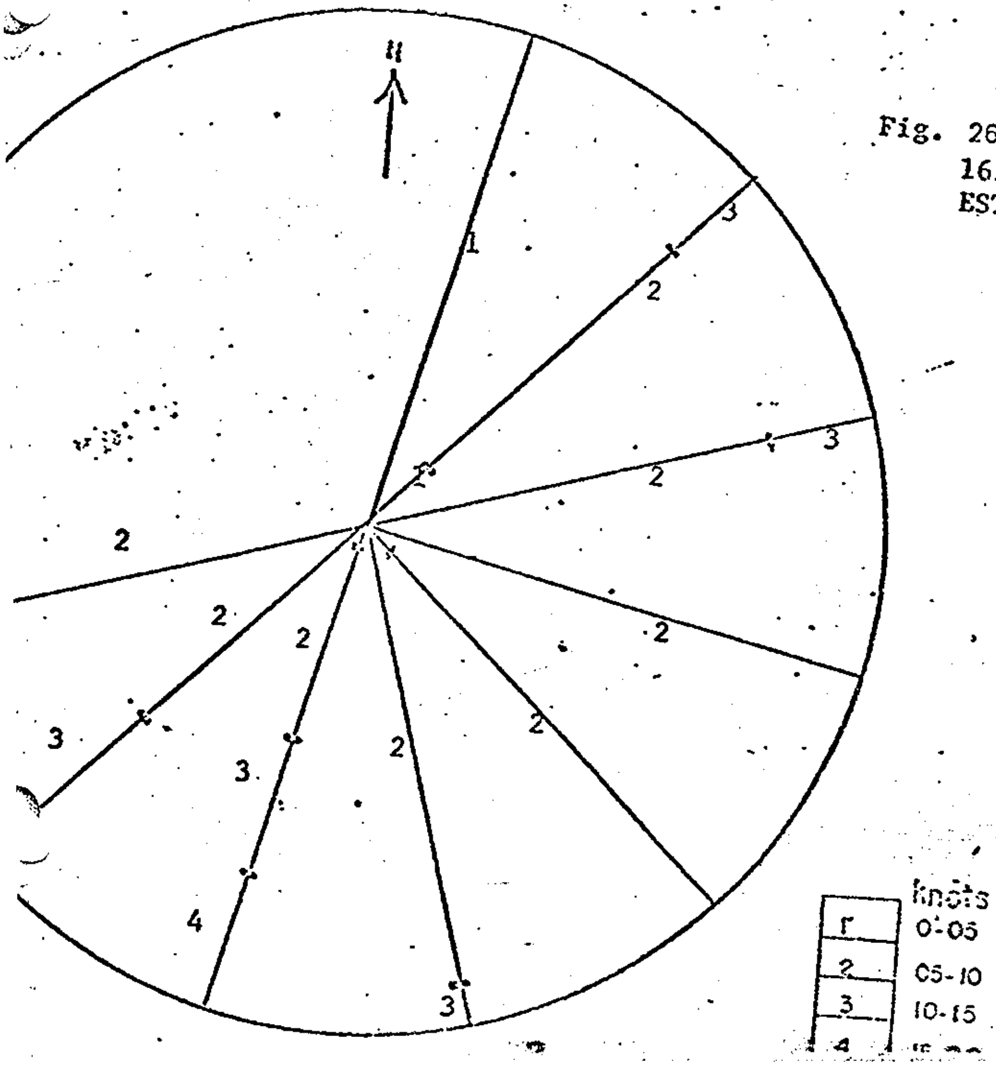
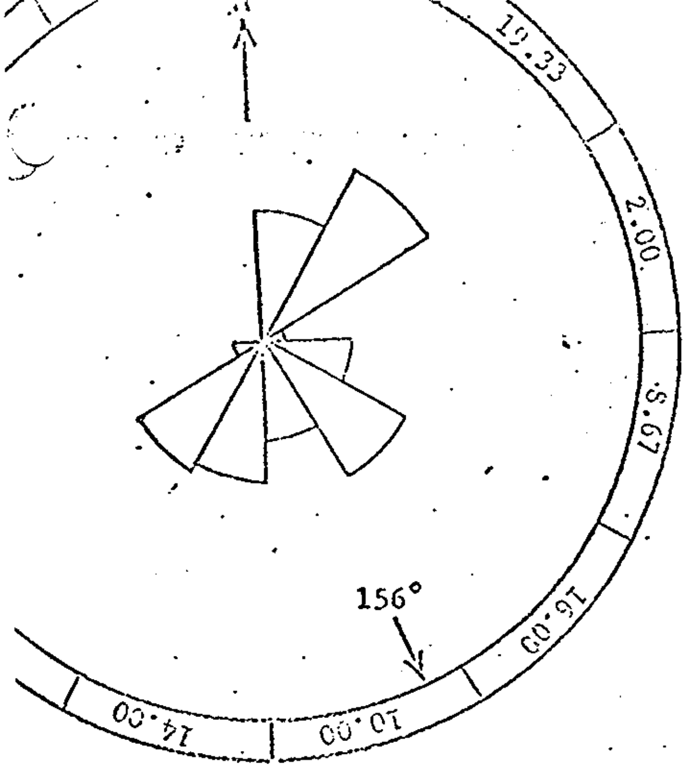
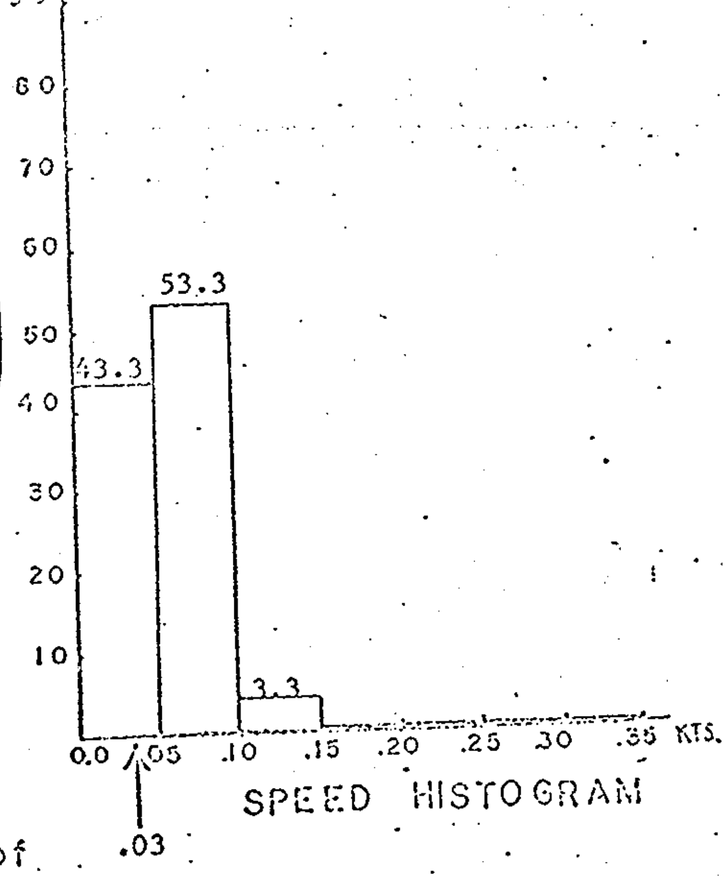


Fig. 26 Current meter records 1630EST July 22- 1720 EST July 23,1970



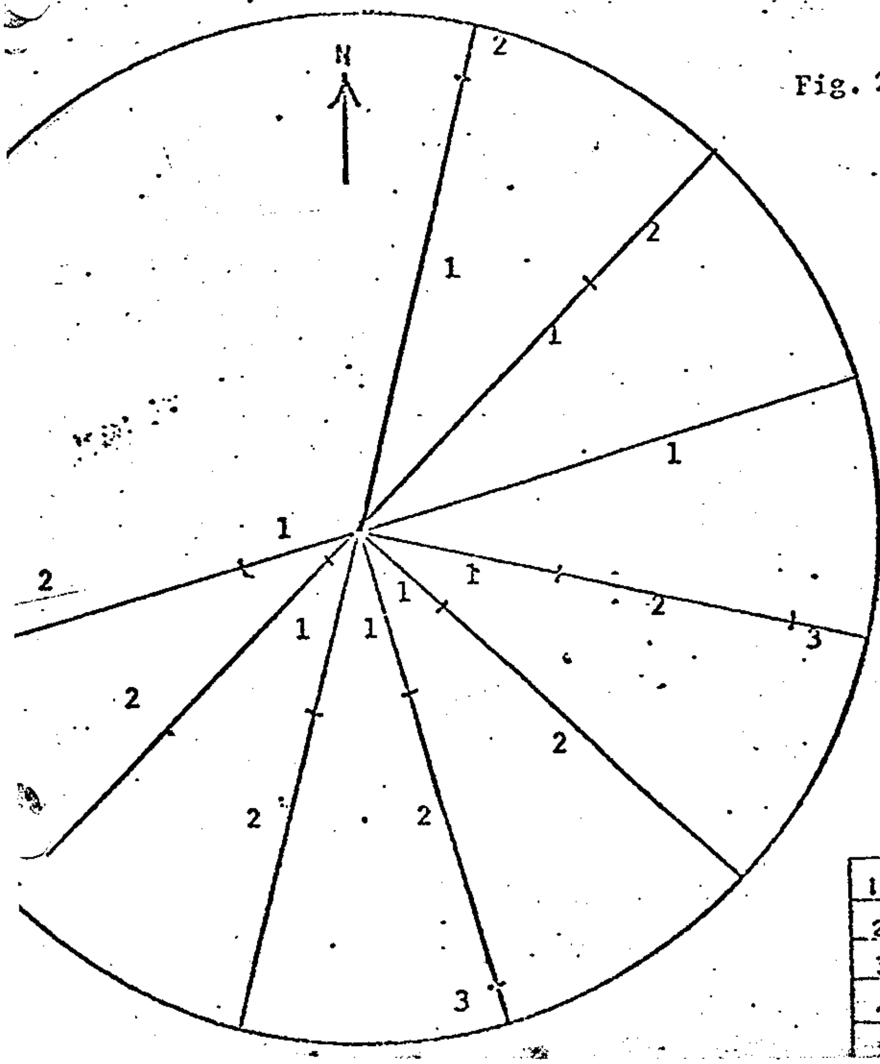
TION HISTOGRAM (radii = %)

indicates speed + direction of non-tidal drift



SPEED HISTOGRAM

Fig. 27 Current meter records
1730 EST July 23 -1820 EST
July 24, 1970



	knots.
1	0-05
2	05-10
3	10-15
4	15-20
5	20-25

The general picture of circulation emerging from these limited measure-s at the dumpsite indicates that this location is equally under the nfluence of tidal motions in and out of Narragansett Bay and the east-est tidal motions in Rhode Island Sound. Although the pattern may be table for only shorter periods of time, it is characteristic of motions hat can be attained by a combination of two possibly interdependent scillations, as indicated above. Certainly, for the period of measurement, more definite and regular circulation regime results in this nearshore cation than at the offshore location studied by Shonting (1969). Pattern tation, with a simulatanteous net movement decrease, is also indicative flows that could arise from two oscillations. The considerable decrease velocities in all directions, at a time of the month when tidal heights e maximum, further underlines the combined oscillatory nature of the . Depending on amplitude and phase differences of such oscillations, "destructive interference" condition may well serve to effect such a crease in flow velocities. Shonting (1969) postulated that reduced n motions (net transport velocities) at the site studied by him may due to the amplified appearance of tidal motions caused by large-scale turbations. The dumpsite records indicate, however, that such reduced n motions here, and the real amplification of tidal effects, may simply due to the interaction of two oscillatory (semidiurnal) tidal components ociated with Narragansett Bay (N-S) and Rhode Island Sound (E-W).

In summary the following conclusions may be reached about the bottom culation at the dumpsite for the period of measurement:

1) the circulation is dominated by the semidiurnal tidal component,

2) the net transport is the daily average resultant of the tidal flow and is small,

3) the magnitude (speed) of the net, "non-tidal" component of

circulation may depend directly on the interaction of tidal currents in Narragansett Bay and Rhode Island Sound,

4) the direction of the non-tidal net component was consistently SSE, with possible range of transport between 0.7 to 1.9 nautical miles per day,

5) largest instantaneous speeds were recorded in the WSW direction.

Kinematics of surface waves relevant to the sediment distribution

The environment created by water movements of wave origin differs radically from that existing in the absence of wave action. Waves play a dual role in determining the distribution of sediments, acting both as a resuspending (erosion) and transporting mechanism.

Once the dumped sediments settle on the bottom, re-entrainment into the water column is most likely to be effected by water particle motions induced by wave action. Currents in the dump site area are generally insufficient in magnitude to produce resuspension of settled sediments. As soon as the material is put into suspension by waves, it is available to the tidal currents for transport. Wave motion also induces a net transport drift at all depths in shallow water, sometimes referred to as wave current. The wave drift is generally smaller than the instantaneous tidal current. Even so, wave drift may have significance in determining the total displacement of resuspended sediments.

In order to understand the role of waves in sediment transport, some wave theory will be reviewed below. The theory of irrotational Stokes waves seems to represent adequately the observed natural phenomena associated with surface gravity waves. Although wave energy is propagated by the motion of the surface deformation, waves also induce particle motions in the water column as the surface disturbance passes. Particle motions associated with gravity waves consist of an oscillatory motion with a small mass transport velocity superimposed on it in the direction of wave propagation.

The wave induced motion of a particle in deep water is circular at any depth, with the orbital diameters decreasing exponentially from the surface to depth. As the wave proceeds into shallow water, bottom effects elongate the circular orbits, changing their shapes into ellipses. The vertical axes of elliptical orbits decrease linearly from the surface to a value of zero on the bottom. The horizontal axes also decrease, however the change is relatively slower with depth. Shallow water bottom effects start to dominate particle motions when the water depth is less than or equal to half the wave length. The average depth at the dump site results in considering the significant waves passing through the area as shallow water waves. The effect of surface waves will be felt on the bottom most of the time.

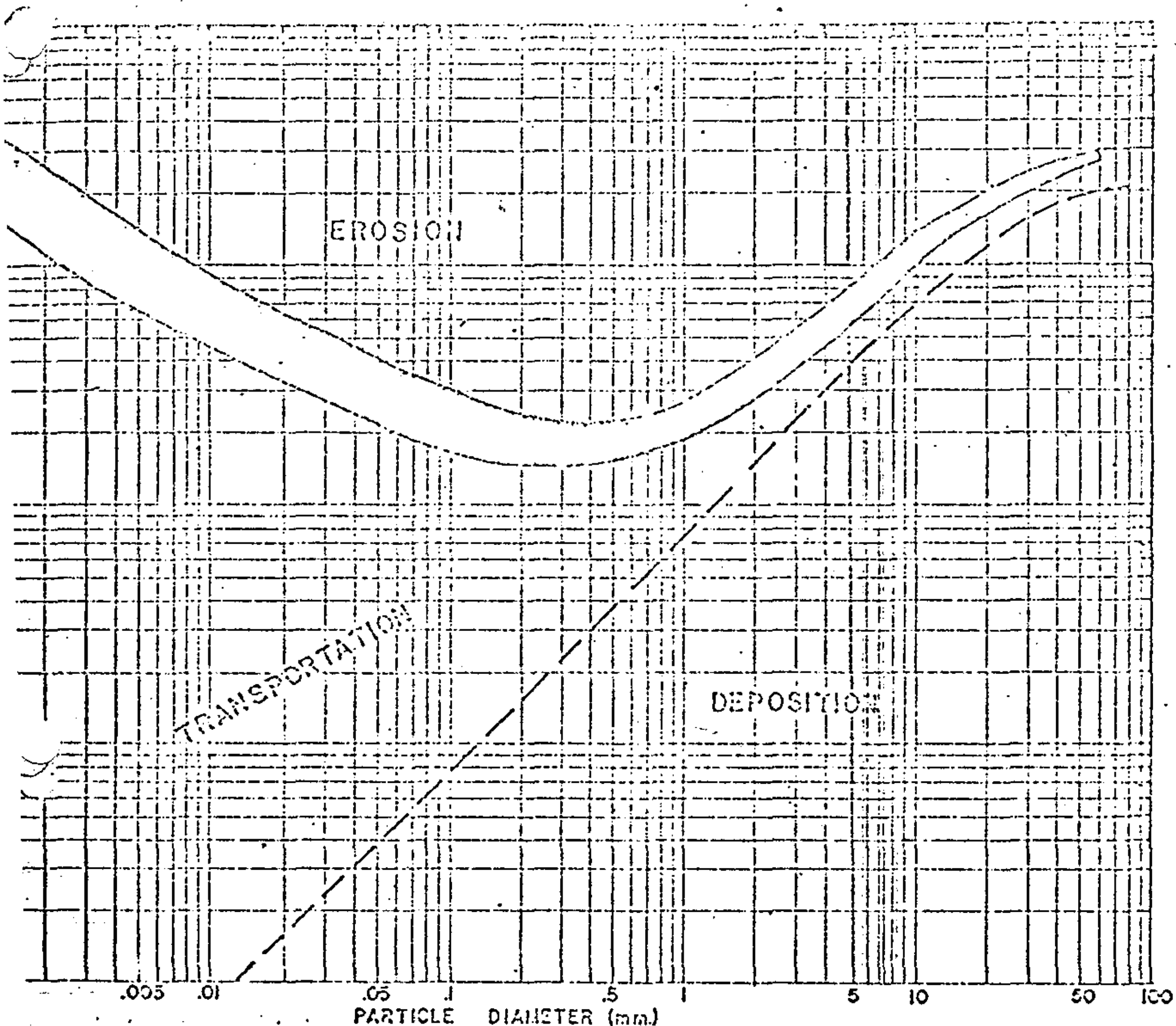
The magnitude of the horizontal component of orbital velocity is the primary factor in resuspending settled sediments. Since the motions are oscillatory, the peak velocity will determine the degree of resuspension of any particular sediment size. The maximum horizontal speed is directly proportional to wave height, and inversely proportional to wave period and depth.

The mass transport (wave drift) velocity mentioned above originates from open orbits developing for higher amplitude waves in a shallow water environment. This result is a measured departure arising from the theoretical assumption of small amplitudes which ceases to be valid when wave amplitudes become large. The particle, therefore, does not return to its original position in the orbit after a full cycle. Theoretical corrections for s of finite height show that the particle motion is greater in its forward movement than in its backward movement. The particle, after one complete wave cycle, arrives forward of its initial position. A second order drift thus develops in the direction of wave propagation.

he potential effects of waves on dumping sediments

Having examined the characteristics of surface gravity waves relevant to resuspension and wave induced transport of sediments, it is instructive to consider the current speeds necessary for sediment erosion and transport. Figure 28 is a reproduction of a graph derived from the experimental measurements of Hjulstrom (1939). The plot specifies within the indicated bounds the current velocities required to erode, deposit and transport particulate matter of different grain sizes. The results apply to unconsolidated silica detritus which has been deposited in the environment normally, i.e., grain-by-grain slow deposition from suspension.

The material easiest to erode is within the 0.1 to 1.0 mm size range. It is expected that if the sediment surface behaves as a normally deposited bottom environment, the smallest velocities that may cause resuspension must be at least the order of 15 cm/sec, or 0.3 knots. From the current record analysis (for the short term measurement at the dumpsite), and from Shonting's (1969) and Cook's (1966) studies, it seems reasonable to conclude that bottom currents alone would not be able to effect resuspension of normally deposited sediment. Yet Morton (1967) indicates an ble presence of suspended sediments in Rhode Island Sound waters, ived from various natural sediment sources in the area. In this light, necessary to examine the extent to which wave action in the Rhode and Sound area is capable of developing the required bottom orbital



ig. 28 Current velocity necessary for erosion, transportation, and deposition of sediments of various particle diameters. (Hjulstrom, 1933).

... are effective in resuspending deposited sediments. ...ble wave data which provides estimates of the percentage ... maximum partical velocities exceed 0.3 knots in the area ... sources. Hogben and Lumb (1967) present a large set of ... of wave height, period and direction made from many ..., compiled according to internationally standardized ... The data is presented in tabular form for large areas over ... conditions are assumed relatively homogeneous. Oviatt ... presents wave data recorded at the Point Judith Coast ... between July, 1968 and February, 1969.

... heights and periods increase in the winter months, and greatest ... sediments can be expected at that time. For geologically ... waves, the heights vary from 1 to 10 feet and the periods are ... second range from July to February at Point Judith.

... and Lumb (1967) the wave induced maximum particle ... exceed 15.2 cm/sec (~0.3 knots) 32 per cent of the time ... Island Sound for 100 feet of water depth. In addition, ... exceed 30.5 cm/sec (~0.6 knots) 18 per cent of the time ...

...lation of calculated values fixes the wave heights ... maximum bottom particle velocity of 15.2 cm/sec ... period waves at 100 ft. water depth.

... (sec):	7	10	13	16	19
... (ft.):	7.08	2.99	2.34	2.12	2.00

... recorded at Point Judith fall within the ... above. In fact, during the storm of November ... the larger waves were capable of producing bottom velocities between 15 to 30 cm/sec at 200 ft. These larger waves occurred for approximately 6 per cent of the time during the storm, constituting 1.7 hours of real time of a 27 hour recording period.

The statistical evidence indicates that resuspension activity by waves should be relatively important at the roughly 100 ft. depth of the dump site. This seems valid for most of the year, but such activity is especially significant during the winter months. Morton's (1967) results agree with thiss degree of activity and indicate that resuspension by currents and waves produces significant concentrations of suspended sediments in the water column.

It is difficult to assess the effectiveness of local waves in transporting suspended sediments out of a given area. A theoretical transport velocity resulting from averaging over the 5 periods in the tabulation above (waves which all produce velocities of 15.2 cm/sec) results in a new daily displacement of 235 feet. This is small compared even to the net tidal velocity which can result in a maximum daily displacement of 2.4 n.m., as calculated from the dump site current measurements.

Assessment of physical erosion mechanisms on dump site disposition

Referring to Figure 28 and to mechanical analyses performed on cores (obtained from the dump site in the summer of 1969), there is reason to believe on the basis of current and wave evidence, that substantial alteration of the sediment distribution should have taken place. Roughly 80-90 per cent of sediment grain sizes in most samples fall in the 0.1 to 1.0 mm. range for which erosion velocities are minimum. Currents and waves acting together would pose no difficulty to the erosion of the dumped material in theory (as discussed above). Bathymetric surveys over the past two

...ns and recent observations of the spoil surface indicate that this is ...ot the case.

The reasons for the ineffectiveness of theory and physical measure-...ents to predict the state of the dump site configuration reside partially ...n the lack of extensive measurements, but more basically in the mode of ...eposition and physical disposition of the dredged material. Some of ...hese factors and conjectures on dredged sediment behavior are outlined ...elow.

1) The dredged sediments were compact and relatively free of water. The angular appearance of the dredged materials on barges attested to this.

2) Although most of the material was comprised of fine fractions, the spoil samples contained granules and pebbles. Lumps of clay were also fairly common. These erosion resistant fractions may have sheltered the finer matrix from erosion.

3) The mode of deposition allowed the dumped material to stay together. Probably only a small amount of spoil went into suspension during dumping. Most of the material was deposited as a mass unit.

4) Compaction may have taken place in the barge where the bouyant effect of water on original surface layers was absent.

5) The sediment surface of the dumping area was probably stabilized by selective removal of fines from the suspended fraction which orig-inated at the time of the dump. Heavier unconsolidated fractions, put into suspension by the precipitous nature of the dumping process, settle faster than the fine suspended matter. The graduated sorting of the surface layer results in the erosion of smaller sizes first, which leaves the coarse material as a pavement, or lag deposit.

This erosion and lag deposit formation would be expected to take place during the winter.

6. Tube building benthic organisms may have produced further erosion resistance on some parts of the dumping area. This effect will become more important when colonization of the spoil is complete.

Keeping these considerations in mind, it may be concluded that Hjulstrom's (1939) curve is not readily applicable to the theoretical prediction of dump site disposition on the basis of presently available physical data. Both the mode of deposition and the nature of the dumped material invalidate the minimum values of current velocity required to resuspend the dredged sediments for all particle sizes.

Under certain circumstances currents and waves will result in the transport of fine materials from the dumping grounds. This may occur at the time of the dump or during a period of storm activity. Considering the distance to shore and transport velocities, it is likely that no larger size particles will reach the beaches before these would resettle. Smaller fractions could reach the shore, but turbulent wave action in the breaker zone, especially during storms, acts as an effective barrier to deposition of fine materials. These materials will eventually find a depositional area where the sediment structure is similar in nature.

<u>Summary</u>

1) Currents in the dump site region are dominated by the semi-diurnal tide. Instantaneous bottom currents rarely exceed 0.3 knots, whereas the net tidal transport velocity is no greater than 0.1 knots.

2) Currents alone are not effective in resuspending sediments.

REVIEW OF SOME DIRECT EFFECTS OF SPOIL DUMPING ON MARINE ANIMALS

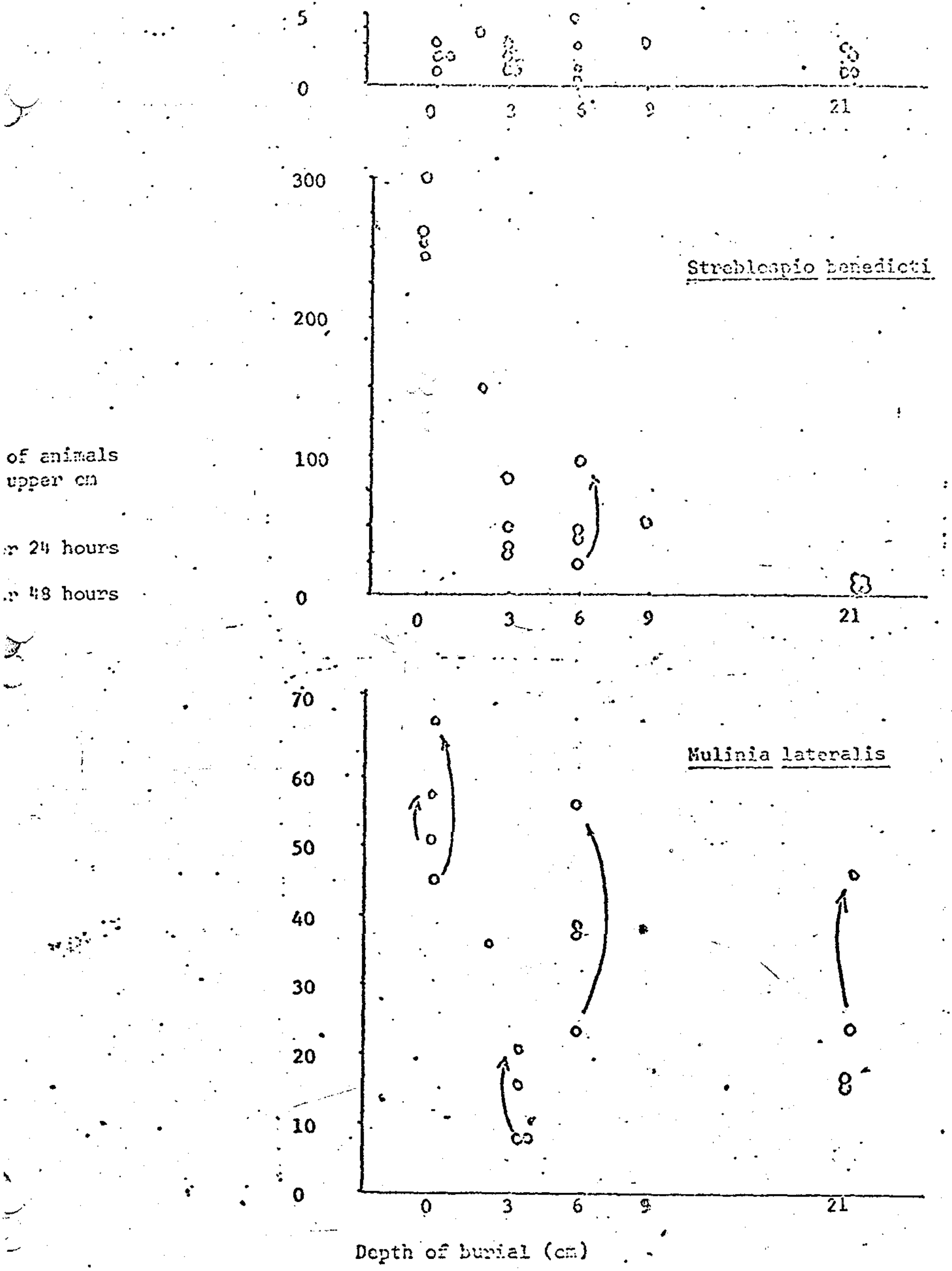
Burial

From a knowledge of the behavior and morphology of an animal under natural conditions it is possible to predict its relative ability to resist the pressure of an added layer of sediment and to burrow to the surface. Nephtys incisa, a large active polychaete, burrows freely through dense sediment. This species is expected to attain the surface after relatively deep burial. Bivalves of the genera Macoma, Yoldia, and Nucula which move vertically are also expected to be able to recover from burial. Glude and Landers (1955) found no mortality of the hard clam (Mercenaria mercenaria) as the result of smothering from silt raised by shellfish dredging operations.

Attached sessile species are killed by burial. There have been numerous instances in which valuable oyster grounds have been destroyed as the result of either direct burial by the dumping of dredged spoil or by the sedimentation of silt raised by dredging operations (Masch, 1965; St. Amant, 1950).

Although attached bivalves were absent from the dump area, several species were present that have little or no ability to burrow. Shafer (1962) referred to these as "Liberosessil forms". Arctica islandica and Astarte borealis, which are found in the dump site area, were considered to be of this type. These animals are probably killed by a few centimeters burial.

Smaller animals of any type have the greatest chance of being destroyed. The fate of colonies of ampeliscid amphipods is of special interest because of the effect of their tubes in determining the nature of the sediment surface. They are not adapted for burrowing and are probably destroyed by shallow burial. They are, however, able to extend their tubes above a rapidly aggrading surface. Evidence of this was found in buried layers



Results of burial experiments with three species.
Arrows mark increases in the number of animals reaching the surface in 24 and 48 hours in the same aquarium.

of tube underlying present surface colonies close to the dump site (grabs 33 and 36). Harrison (1967) observed a weekly deposition of more than one half inch around amphipod tubes. The effects of burial on offshore animals is not known at present.

A burial experiment was conducted with animals from the lower Providence River in order to assess their likelihood of surviving the dredging and dumping operation and becoming established on the offshore site. Sediment samples were taken with a Smith-McIntyre bottom grab at Station PS 5 (Figure 14). The upper 3 cm containing most of the animals was separated from the dense subsurface sediment. Three cm of the mixed surface sediment was placed in 10 small aquaria (27 X 14 cm) and buried with up to 21 cm of subsurface sediment. One half of the surface was sampled after 24 hours and the remainder after 48 hours. The samples were passed through a 0.75 mm sieve and the retained animals counted. Fourteen species were recovered but only three were abundant enough to be considered. The results are shown in figure 29.

Nephtys incisa attained the surface in less than 24 hours from all depths. Streblospio benedicti, a very abundant, 1 cm long, tube-dwelling polychaete, was able to reach the surface through up to 6 cm of sediment, but not through 21 cm. Mulinia lateralis, a small filter feeding bivalve, reached the surface from all depths but many individuals took over 24 hours. It was concluded from this experiment that detectable numbers of these species probably reach the surface of the dumped spoil.

Turbidity

The increased concentration of suspended particles in the water during the dumping operation and after resuspension could affect animals by causing mechanical damage to respiratory surfaces and by diluting the food particles utilized by filter feeders with non-food particles.

Aquatic animals are able to tolerate rather high concentrations of suspended sediments for short periods. Rogers (1969) investigated the effects of exposure to suspended mineral solids on four species of estuarine fishes. Twenty-four hour median tolerance limits ranged in value from more than 300 gm/liter for _Fundulus heteroclitus_ to 50 gm/liter (50,000 ppm) for the stickle-back (_Apeltes quadracus_). He noted that damage to fish was more a function of the presence of large angular particles in suspension than the optical turbidity of the suspension. Ritche (1970) held four species of fish in cages close to the effluent of a hydraulic dredge in upper Chesapeake Bay and recorded no lethal factors. He also examined the gills of 11 species of fish caught in the spoil disposal area and found no tissue damage.

Saila, Polgar, and Rogers (1968) exposed lobsters (_Homarus americanus_) to suspensions of up to 3,200 ppm of unpolluted estuarine silt and 900 ppm of Providence Harbor spoil sediment for 24 hours. No mortality was recorded which was directly attributable to sediment concentration. In a bottom choice experiment made as part of the present study, four groups of eight lobsters were held for 48 hours in a large tank partially floored with Providence Harbor silt. As they burrowed in the silt the lobsters passed dense clouds of sediment through their gills. No mortality was recorded during the experiment or in a two week period afterward. In tests at the Sandy Hook Marine Laboratory (1969) lobsters and crabs (_Cancer irroratus_) held in aerated aquaria with sewage sludge and dredge spoil remained alive for extended periods. It is concluded from these studies, and from observations indicating that mass resuspension of spoil probably occurs only during periods of heavy swell, that there will be no mortality of fish and lobsters in the dump site area caused by sediment load alone.

Until a sandy bottom is formed over the spoil dump, there will be more fine grained particles in suspension there than there would be over natural bottom in the area. Filter feeding benthic invertebrates take their food from water immediately off the bottom. Any excess suspended sediment must be either injested or sorted from food particles before injestion.

Selective feeding ability has been found in many filter feeders. It has been particularly well described in estuarine bivalves where sorting takes place on the gills and labial pulps. Rejected particles are entrapped in mucus strands and passed out as pseudo-feces (Graham, 1957; Galtsoff, 1964; Vervey, 1952; Yonge, 1954). It is likely that species found outside the estuary are less efficient at limiting their intake of mineral matter and may suffer a selective disadvantage on a bottom with excess fine sediment.

Anoxia

Sewage sledge and the highly organic sediments of inner harbors have a high oxygen demand. Reduced chemical compounds take up oxygen immediately, while bacteria consume organic matter producing a biological oxygen demand continuing over a longer period. If these sediments are dispersed in a body of water with restricted mixing, dangerously low oxygen levels should be produced. Measurements of dissolved oxygen over the sewage sludge dumping grounds in New York Bight (Sandy Hook Marine Laboratory, 1970) showed reductions from 7 ppm to less than 1 ppm three feet above the bottom. The factors important in the formation of anoxic bottom waters are rate of organic matter input, particle dispersal, and water mass circulation.

The organic matter content of Providence River sediments varied from a high of 10% in the inner harbor to a low of 1-3% in upper Narragansett Bay. Much of this organic matter consists of cellulose plant remains which are highly resistant to breakdown. Hexane soluble fractions, which made up to 10% of the organic matter in Providence Harbor samples consisting of 4-5% organic matter (Saila, Polgar, and Rogers, 1968), are only slowly metabolised by bacteria. Dispersal of spoil during dumping is probably minimal as the dense material plunges immediately to the bottom forming a layer several feet thick. Only the upper few millimeters of this layer can contribute to oxygen removal from the water. Although only moderate currents pass over the bottom (.05-.30 knots), the volume of water and of dissolved oxygen seems ample to rapidly oxidize the surface of the spoil.

Animals buried by anaerobic sediments may die of anoxia before they can reach the surface. The most vulnerable group of animals is probably the small crustaceans whose response to oxygen deficiency is increased ventilation. Bivalve molluscs incur oxygen debt, while some polychaetes lower their activity and metabolism when oxygen is low (Nicol, 1960). These mechanisms would aid escape from burial.

Sediments with a high percent of organic matter will remain anaerobic beneath the surface. Bader (1954) states that more than 3% organic matter in sediments may limit the concentration of non-tolerant infauna. The species found in Providence Harbor are examples of animals physiologically and behaviorally adapted for survival at low oxygen levels. Bivalves (Mya) and polychaetes (Streblospio and Pectinaria) occupy tubes and have efficient pumping mechanisms to carry dissolved oxygen to respiratory surfaces. Adults and larvae of Polydora ligni can tolerate oxygen concentrations as low as 1.5-2.5 ppm and 0.6-2.1 ppm, respectively (Richards, 1969). The deposit feeding polychaete Capitella capitata survives in highly polluted low oxygen sediments throughout the world (Reish, 1959).

Hydrocarbons

Saila, Polgar, and Rogers (1968) reported concentrations of 0.54-0.76% (dry weight basis) of hexane extractable material in spoil samples from Providence Harbor which had been selected for analysis because of high organic matter content. Farrington (1971) determined the hydrocarbon fraction of sediments from the Sabin Point area of the Providence River. The average value for 9 determinations was 0.31%. Gas chromatography indicated that these hydrocarbons had the characteristics of "aged petroleum". They were mostly cyclic saturated compounds of low biochemical activity. More toxic aromatic and low-boiling saturated hydrocarbons had apparently been lost by evaporation and biochemical modification.

The quality of these hydrocarbons and the fact that most of the spoil on the dump site surface came from unpolluted areas decreases the possibility of adverse effects to animals colonizing the spoil. Concentrations below toxic levels may have ecological effects, however. Blumer (1969) has suggested that certain oil fractions in very low concentrations could interfere with the chemical senses of marine animals. These mediate finding of food, escape from predators, selection of habitat, and sex attraction. On the spoil dumping ground hydrocarbons could change the settling pattern of the larvae of benthic invertebrates or interfere with the ability of lobsters and crabs to find food.

Non-polar chemicals are many times more soluble in oil than in water and will become concentrated in sedimented oils. Hartung and Klingler (1970) reported calculated and empirical concentration factors of 1 million for DDT in an oil-water system. Although traces of dieldrin and chlordane have been found in quahogs from the Providence River (R.I. Dept. of Health), total pesticide input probably has been quite low (Olney, 1970). Polychlorinated biphenols, which are widely used in plastics manufacture, are as toxic as chlorinated pesticides and would be expected to be concentrated in oil.

Toxic substances in oil would have varying effects on different species on the dump site. Detritus feeders and their predators would assimilate higher concentrations of these substances than would filter feeders which are consuming phytoplankton from unpolluted waters (Odum et al., 1969; Woodwell et al., 1967). Crustacea are particularly sensitive to pesticides and heavy metal poisoning (National Marine Water Quality Laboratory, 1970) and may be the first group to show the effects of sediment pollution.

Heavy metals

Toxic metals probably enter the sediments of Providence Harbor through effluents from metalworking industries and sewage treatment plants.

At the National Marine Water Quality Laboratory, West Kingston, Rhode Island, various workers are studying the concentrations of heavy metals in the sediments and benthic invertebrates of the Providence River and the toxicity and histopathologic effects of these metals on invertebrates and fish. The metals being studied include gold, silver, copper, cadmium, zinc, lead, chromium, nickel and mercury. Each of these metals has unique physical-chemical and biochemical characteristics.

Cadmium is attracting special interest because of its high solubility in seawater, tendency to accumulate in organisms, and synergistic toxicity with zinc and copper (National Marine Water Quality Laboratory, 1970; Shuster and Pringle, 1968). Recent analyses of Providence River water near plating plant effluents have shown very high cadmium and zinc concentrations.

Phelps (1971) found that uptake of several metals was high in polychaetes overwintering in subsurface sediments. Apparently both the physiological state of the animals and the physical-chemical characteristics of the interstitial water determined the rate of uptake.

While it is possible that the levels of toxic metals in heavily polluted sediment may cause the death of some infaunal species, the possibility of these becoming concentrated in species eaten by man is probably of greater importance in consideration of spoil dumping at sea.

The levels of metals in the surface sediments of the dump site are unknown. It is believed that most of the spoil from areas where metal pollution might exist has been buried by spoil from unpolluted areas.

Change in grain size distribution

The densest populations of subtidal filter feeders are found on well sorted fine sand bottoms, an indication of an environment with moderate circulation and physical stability (Sanders, 1958; Carriker, 1967). Deposit feeders, those that either select food particles from the sediments or injest the sediment completely, are more abundant on fine sediments where more food is found on the bottom than is available from weak currents. Sanders (1956, 1958) correlated high numbers of small deposit feeders with sediments with 20-40% clay. The type of tube, the depth of burrowing, and the type of food collection of benthic fauna are adapted to both the hydrographic regime and to sediment characteristics which are correlated with the hydrography. When fine grained spoil sediments are dumped in an area which normally supports a sandy bottom community of filter feeders it is not possible to predict, a priori, whether sediment characteristics or hydrographic characteristics will determine the make-up of the colonizing community.

Any cobbles or boulders on the surface of the spoil will be available for colonization by barnacles, sponges, hydroides, and other epifauna.

THE EFFECTS OF SPOIL DUMPING ON THE BENTHIC INVERTEBRATES OF RHODE ISLAND SOUND

Introduction

Studies of environmental disturbance can emphasize the response of either individual species or of the assemblage of animals in an area taken as a whole. This study emphasizes the latter, or synecological approach. The variables at this level include species diversity, patterns of species abundance, and similarity between collections. It is believed that a realistic assessment of disturbance to an environment can be made at this level. Before valid conclusions can be made about the effect of dredge spoil on any individual species it is necessary to have a through knowledge of its spatial and temporal distribution, feeding habits, and ability to select substrate. This information is available for few estuarine species and probably no offshore ones.

Any natural sea-bottom has an assemblage of invertebrate animals living in the sediment (infauna) and on the surface (epifauna). Forty to a hundred species of macrobenthic species might be found on a square meter of bottom in an estuary or on the continental shelf in temperate regions. Macrobenthic species are often operationally defined as those animals which are retained on a 1 mm sieve. The species found, and their relative abundance, vary with the properties of the water and sediment. This variation is neither continuous nor random. Reoccuring assemblages or communities characterized by the same dominant species and having the same pattern of subdominants cover wide areas. The muddy bottoms of Long Island Sound, Narragansett Bay, and Buzzards Bay all support populations of *Nephtys incisa*, a polychaete worm, and *Nucula proxima* and *Yoldia limatula*, deposit feeding bivalves. Sanders (1956, 1958) named this the *N. incisa-Y. limatula* community in Long Island

Sound and the *N. incisa* *N. proxima* community in Buzzards Bay. All three of these estuaries have ampeliscid amphipod colonies on sandy bottoms. Sanders (1958) named these *Ampelisca* spp. communities.

Such assemblages were first named only as statistical units to aid in the determination of the fish food potential of the sea floor (Thorson, 1957). The hypothesis was soon made, however, that there was biological interaction and accommodation within such communities.

There is variance of opinion as the degree of this interaction. One view holds that the species found in an area are merely all adapted to the level and variability of the physical parameters of the environment and have successfully competed with the other species for space and food. The contrasting view is that the community is a superorganism whose parts (the species) have naturally evolved to provide efficient use of space and energy and to adjust for environmental variations in a way that preserves the community. The groups of animals found in the polluted and physically variable Providence River can best be described in the first way. The communities of the more stable Rhode Island Sound environment may be expected to show more species interaction.

Neither the theory of species interaction in benthic communities, nor the validity of the measures used to indicate this interaction, have been rigorously tested. This analysis of the recolonization of spoil covered bottom provides an opportunity to test the utility of some of these measures.

Methods

Quantitative samples of the bottom were taken with a 1/10 M^2 Smith-McIntyre grab. This grab has been shown to be reliable in rough waters (Lie, 1968) and efficient in sampling motile epifauna (Wigley, 1967). One or two cores with a 28 cm^2 surface area were taken from the grab for sediment analysis. In several samples these were used for counts of small, very abundant species. The water draining from the sampler was collected and filtered to retain any amphipods which had left the sediment surface.

The sediment was brought back to the laboratory and gently sieved with salt water through a nylon screen with 0.75 mm mesh size. This size is a compromise between a 1 mm mesh which would retain fewer animals and a 0.5 mesh which would retain large quantities of sediment and detritus. These screens were clamped onto a box frame with an area of one square foot. The animals were relaxed with 7% $MgCl_2$, fixed with 10% formaldehyde, and stained with rose bengal while still on the screens. Leaving the animals on the screens until they are fixed and stained minimizes loss of small species and damage to soft bodies ones.

Animals were separated from the coarse sediment particles and plant detritus remaining on the screens, sorted to species and counted. Identifications were made using Smith (1964) for all groups; Pettibone (1963) and Hartman (1964) for polychaetes; Abbot (1954) for mollusks; and Kunkel (1918), Chevreux and Fage (1925), and Mills (1967b) for amphipods. The species list will be verified as part of a continuing Rhode Island program.

This report is based on the results from stations for which species counts have been completed for duplicate or triplicate samples. Partially counted samples from the Providence River, a series of samples from near the alternate dump site off Point Judith, and qualitative grab samples from the dump site all contributed to an understanding of the representativeness of those samples reported on.

Results and Discussion

Fauna of the Providence River: Various parts of the dredge spoil source area were sampled to find what animals were being introduced offshore with the spoil. These data also indicate the general level of pollution in the spoil source area.

It was possible to distinguish the assemblage of species found in Providence Harbor from those of the seaward parts of the dredge area. The salinity of the surface water of the harbor varies from <10-27 o/oo (Hicks, 1959). No animals were found in samples from the harbor bottom itself. Recent dredging activity, an almost liquid surface sediment layer, and low oxygen concentration all contributed to the absence of macrobenthos here. Grab samples taken from shallow bottom (3-10 feet deep) on the east side of the harbor (PG 1, PG 2, PG 4, PG 6) and from south of Fields Point (PS 4) yielded considerable numbers of the following species:

Nereis succinea - deposit feeding polychaete
Streblospio benedicti - deposit feeding polychaete
Mya arenaria - suspension feeding bivalve
Macoma balthica - suspension feeding bivalve
Nassarius obsoletus - deposit feeding gastropod

Polydora ligni, a deposit feeding polychaete and *Palaemonetes pugio*, an omnivorous decopod shrimp, were also present.

These species and genera are familiar pollution resistant organisms. Wass (1967) compares *P. ligni*, *S. benedicti* and *N. succinea* to weeds "which proliferate over broad areas of man's disclimaxes". Dean (1970) identifies *S. benedicti* as a possible key pollution indicator organism. It is necessary to consider, however, whether these species, all adapted to survive in highly variable environments, might be found in the Providence River if it were unpolluted. These same species are abundant in the brackish waters of unpolluted estuaries where salinity varies from 0-10% and in salt marshes areas where salinity is low and variable and oxygen is sometimes limiting

(A. C. Myers, 1970).

It is necessary to consider the species missing from a natural brackish water fauna in order to show the effect of pollution. About 20 species would be expected in this salinity zone in an undisturbed environment (Hedgpeth, 1957; Sanders et al., 1965; Stickney and Stringer, 1957). Some important species which are absent are the oyster (Crassostrea virginica), the polychaetes Scolecolepides viridis and Pygospio elegans, the mollusks Gemma gemma and Hydrobia sp. gammarid amphipods, and all intertidal bivalves and barnacles.

It may be concluded that the fauna of Providence Harbor is limited not only by low oxygen concentrations and low and variable salinity, but also by toxic materials in the water and/or sediment.

Below Fields Point the salinity varies from 20-30 o/oo and the water quality is considerably higher than in Providence Harbor. Table 6 lists 30 benthic species collected in a limited number of samples from this zone. The shallow bottom on either side of the dredged channel has high densities of quahogs (Saila et al., 1967). Although stations PS 1 and PS 2 yielded quahogs, the sediment was soft, black and anarobic below the surface. The fauna was somewhat limited and included Capitella capitata, an indicator of high organic matter concentration.

The bottom of a part of the channel which had not been dredged yet, sampled at stations PS 3 and PS 6, had a characteristic appearance. Lineatious and a lag deposit of empty shells indicated an appreciable current. The sediment was compact and the upper 5 mm was oxygenated. The following speeds were abundant at these stations:

Nephtys incisa	Deposit feeding polychaete
Streblospio benedicti	Deposit feeding polychaete

Capitella capitata	Deposit feeding polychaete
Heteromastus filiformis	Deposit feeding polychaete
Glycinde solitaria	Deposit feeding polychaete
Pectinaria gouldi	Deposit feeding polychaete
Nassarius trivittatus	Deposit feeding gastropod.
Mulinia lateralis	Suspension feeding bivalve
Yoldia limatula	Deposit feeding bivalve

The rapid sedimentation taking place in these areas apparently supplies an abundance of food to deposit feeders. As a result of the two-layered hydrographic structure of the estuary, bottom water with relatively high oxygen concentration and relatively constant salinity flows north, providing a much less polluted environment than that found in the surface waters.

Benthic communities of Rhode Island Sound: The benthic invertebrate communities of Rhode Island Sound are easily separated from those of Narragansett Bay (Phelps, 1958). Although they have some species in common with the estuarine communities, often different species of the same genera are found on analogous bottom types. These species are adapted for life in full salinity sea water with less temperature variation and lower average suspended sediment load than is found in estuaries.

The sediment in the dump site area consists of fine sand. Medium sand is found in shallower water to the north and east. The silt content increases gradually toward the west and reaches a maximum just east of Point Judith (Fig. 15). Stations were chosen which would be characteristic of the various sediment types in order to show whether they supported distinct faunal assemblages. A knowledge of these assemblages is necessary to recognize the source of species colonizing the spoil.

Various numerical measures have been used to show the similarity between collections of animals. In this report the percent similarity of species composition is used as an index to show how closely pairs of samples are related. This index was used by Sanders (1960) and Wiener (1960) with macrobenthic and meiofaunal samples from Buzzards Bay. It is considerably more straighforward than indexes using prominance valves, (Pearson et al., 1967) or information theory (Horn, 1966). Percent similarity = Σ min (a,b) in which a and b are, for a given species, the percentages of samples A and B which that species represents. This index has been criticized as overvaluing shared dominant species to the neglect of differences in over-all community composition (Whittaker and Fairbanks, 1958).

A percent similarity for each pair of samples compared in this report are placed in a matrix (Figure 30). The samples are rearranged so that closely related samples are in groups. Figure 31 shows the percent similarity after the dominant A. agassizi was removed from the records of five samples. Sanders (1960) obtained an average index value of 69.3 in replicate samples from a single station and 31.2 and 37.2 in samples from distinct community types in Buzzards Bay. In this study three faunal assemblages were identified on the basis of visual appearance, dominant species, and similarity between samples of over 30 percent.

The samples 7-1 and 7-2 are representative of the clean medium-sand found east and north of the dump site. The number of individuals and species from these samples were 426/29 and 351/25. Some characteristic species were:

Byblis serrata	suspension feeding amphipod
haustoriid sp.	detritus feeding amphipod
Cirolana concharum	scavenging isopod

100																
88	100															
34	29	100														
08	03	45	100													
07	03	40	92	100												
14	11	57	55	52	100											
14	10	54	47	46	84	100										
13	09	25	15	14	48	58	100									
05	04	09	03	02	23	25	39	100								
07	05	10	02	02	20	21	30	61	100							
05	04	09	03	02	22	30	30	49	63	100						
06	07	17	07	05	31	36	43	38	44	23	100					
02	00	07	04	01	04	05	05	11	17	07	30	100				
01	01	11	07	04	06	06	07	8	13	07	17	27	100			
06	04	10	05	03	11	12	11	11	06	05	06	03	05	100		
07	07	13	06	03	15	15	17	16	06	05	13	03	04	73	100	
05	03	07	06	04	10	10	09	12	05	03	07	04	06	72	77	100
7-1	7-2	7-3	14-2	14-1	11-1	11-3	11-2	10-1	10-2	10-3	8-2	8-1	8-3	9-1	9-2	9-3

clean sand — amphipod tubes — sand/silt/clay — sand/shell — silt

dredge spoil

e 30 Matrix of faunal similarity indexes between 1/10 M^2 samples.

similarity 50-100%

similarity 30-50%

	7-1	7-2	7-3	14-2	14-1	11-1	11-3	11-2	10-1	10-2	10-3	8-2	8-1	8-3	9-1	9-2
7-1	100															
[illegible]	88	100														
7-3	33	36	100													
4-2	09	09	43	100												
4-1	10	08	39	65	100											
1-1	11	10	39	35	34	100										
1-3	11	09	34	31	33	75	100									
1-2	13	09	23	24	21	58	68	100								
)-1	05	05	13	16	13	33	37	39	100							
)-2	07	05	14	11	03	32	31	30	61	100						
)-3	05	04	13	12	15	37	38	30	49	63	100					
-2	06	07	21	23	16	39	42	43	38	44	23	100				
	02	00	10	19	12	06	08	05	11	17	07	30	100			
	01	01	15	26	17	09	10	07	08	13	07	23	27	100		
-1	06	04	13	16	13	15	15	11	11	06	05	606	03	05	100	
-2	07	07	14	20	13	21	19	17	15	06	05	13	03	04	73	100
-3	05	03	08	17	14	13	13	09	12	05	03	07	04	06	72	77

clean sand (7-1, 7-2) — amphipod tubes (7-3, 14-2, 14-1) — sand/silt/clay (11-1 to 8-2) — sand/shell (8-1, 8-3) — silt (9-1, 9-2)

dredge spoil (11-1 to 8-3)

re 31 Matrix of faunal similarity indexes between 1/10 M^2 samples.

* indicates that a record of 1 Ampelisca agassizi was substituted for the actual number.

similarity 50-100%

similarity 30-50%

Echinarachnius parma	detritus feeding echinoid
Jaculella obtusa	detritus feeding arenaceous foraminifera

These species are part of the sand bottom fauna described by Wigley (1968) and Smith (1950) from areas with substantial wave and current activity.

Samples 7-3, 14-1 and 14-2 are closely related. They represent the amphipod dominated bottom surrounding the spoil dump. Station 14 is treated as unaffected by spoil although it is close enough to the dump area to have received some sedimentation of spoil materials. The number of individuals and species from these samples were 1451/49 for 7-3, 3272/44 for 14-1 and 1999/46 for 14-2. Some abundant species were:

Ampelisca agassizi	suspension feeding amphipod
Ampelisca vadorum	suspension feeding amphipod
Byblis serrata	suspension feeding amphipod
Unciola irrorata	detritus feeding amphipod
Leptocherius pinguis	suspension feeding amphipod
Orchomella pinguis	detritus feeding amphipod
Phoxocephalus holbolli	detritus feeding amphipod
Ptilanthura tenuis	detritus feeding amphipod
Diastylis spp.	detritus feeding amphipod

Many polychaete species were represented by a few individuals. Small bivalves were nearly absent. Arctica islandica, a large bivalve which was too scattered to be properly sampled by a 1/10 M^2 grab, seemed to have a distribution correlated with the presence of amphipods.

The dominant and subdominant species of these samples were generally similar to those of the Ampelisca spp. communities which Sanders (1956, 1958) described in Long Island Sound and Buzzards Bay. These samples differed from the more estuarine Ampelisca communities in the dominance of A. agassizi. This species is probably characteristic of silty sands and the [illegible] tinental shelf. Southern New England estuaries support _A. vadorum_ (_A. spinipes_ of Sanders) and _A. verrilli_ (_A. macrocephala_ of Sanders) on sandy bottoms and _A. abdita_ (_A. spinipes_ of Sanders (1958), Phelps (1958), and Stickney and Stringer (1957)) on silty bottoms. Mills (1967) stated that little is known of the choice of substrate or mode of feeding of _A. agassizi_. It is hoped that future studies in Rhode Island Sound will yield more information on the ecology of this species.

The samples from station 9 are representative of the silty area west of Point Judith. The faunal assemblage is very dissimilar from those of the sandy bottom stations. The numbers of individuals and species recovered were 576/41, 562/41, and 484/35. The characteristic species included:

Cerianthus americanus	suspension feeding anthozoan (anemone-like)
Edwardsia elegans	suspension feeding actiniarian (sea anemone)
Bostrichobranchus pilularis	suspension feeding tunicate
Pitar morrhuana	suspension feeding bivalve
Periploma papyratium	suspension feeding bivalve
Nucula delphinodonta	deposit feeding bivalve
Nucula proxima	deposit feeding bivalve
Ampelisca abdita	suspension feeding amphipod
sabellariid spp. (4)	suspension feeding polychaetes
Pherusa affinis	deposit feeding polychaete
Lumbrineris fragilis	deposit feeding polychaete
Clymenella torquata	deposit feeding polychaete
Amenia fusiformis	deposit feeding polychaete
Sternaspis scutata	deposit feeding polychaete
Polycirrus sp.	deposit feeding polychaete

This assemblage included species which occur in silt-clay estuarine sediments (P. norrhusna, N. proxima, A. abdita, Pherusa affinis) as well as species characteristic of silt-clay offshore sediments (S. scutata, Polycirrus sp.). The dominant species, however, were a unique group of suspension feeders adapted for a soft bottom. Although the sediment in this area is soft and muddy the clay content is only 7-10% (McMaster, 1970, Sta. 9 this study). Apparently not enough organically rich particles settle out here to support a dominant detritus feeding population. The current velocity is adaquate to bring food to suspension feeders which are able to find purchase in the soft sediments. These suspension feeders occupy tubes or are buried in the sediment. This contrasts with the epifaunal habit of the familiar anemones, tunicates, and suspension feeding polychaetes found on hard bottoms.

There are several other species which are characteristic of Rhode Island Sound bottoms, but which were not collected in the samples taken in this study. The bivalve Cerastoderma pinnulatum is found on sand bottoms at the mouth of Narragansett Bay (Phelps, 1958). Ampelisca verrilli occurs on sandy silt at the mouth of the west passage of Narragansett Bay (Pratt, 1967). The bivalves Astarte borealis, Cardita borealis, and Astarte undata and the gastropod Colus pygmaea have been collected on silty-sand offshore of the dump site.

A complete analysis of the silty sand fauna of Rhode Island Sound would probably reveal a patchwork of species associations adpated to different hydrographic and sedimentary conditions. Such an analysis would be a formidable task because of the time required to sort and identify the individuals and species in the many samples that would be required.

Fauna found on the spoil: Though spoil dumping was continuing during this study, the center of activity had moved from the center of the dump site to the west corner. Areas of spoil on the southeast edge of the site had been exposed to animal colonization for periods which could have been as long as three years. Stations 8, 10, and 11 form a transect across this area (Fig. 2). The lengths of time that these surfaces had been exposed is unknown. Progressively larger animal populations are found away from the dump center. This could be the result of time of exposure or of distance from the center of dumping activity.

The samples from these stations fall into three general categories on the basis of sediment composition and fauna.

The bottom at stations 8-1 and 8-3 consisted of coarse sand and shell. The numbers of individuals and species recovered from these stations were only 27/8 and 23/10. The species appearing in these samples had two apparent sources. Those probably introduced with the spoil included *N. incisa*, *M. lateralis*, and *N. trivittatus*. *Unciola irrorata* and four other amphipod species and *Sthenelais limicola*, a polychaete, are active Rhode Island Sound species which probably entered this area as adults.

Samples 8-2, 10-3, 10-1, 10-2 and 11-2 were all taken on mixed sand/silt/clay bottoms. The numbers of individuals and species found were 131/14, 603/19, 154/14, 196/20, and 438/26. The fauna was of mixed origin and included:

1) Species entering with dredge spoil - *N. incisa* and *M. lateralis*.
2) Species entering as adults from adjacent areas - *Leptocheirus pinguis* and other amphipods.
3) Species which settled as larvae - *Pitar morrhuana*; *Phoronis architecta* (a lophophorate suspension feeder); *Prionospio malmgreni*, *Eteone longa*, *Tharyx acutus*, and *Heteromastus filiformis* (all small deposit feeding polychaetes present as subdominants in the natural *Ampelisca* community).

Samples 11-1, and 11-3 were taken from spoil with characteristics much like those of the previous group but with many more amphipod tubes. The number of individuals and species found were 1153/53 and 1712/43 respectively. The similarity indexes, calculated with _A. agassizi_ included, relate these samples to the natural _Ampelisca_ community sampled in 7-1, 14-1 and 14-2. When these stations are compared with _A. agassizi_ removed, an affinity is shown between them and the previous group of samples of colonized spoil. The density of _A. agassizi_ in these samples was about 1/4 of that at stations 14-1 and 14-2 (717 and 654 versus 2675 and 1671). _Leptocherius pinguis_, a large amphipod, was found in much greater abundance here than in stations 14-1 and 14-2 (257 and 339 versus 6 and 17). Other species which were more abundant on the newly colonized spoil than on natural bottoms included:

Nephtys incisa	deposit feeding polychaete
Eteone longa	deposit feeding polychaete
sabellarid spp	suspension feeding polychaete
Phloe minuta	deposit feeding polychaete
Prionospio malmgreni	deposit feeding polychaete
Spisula solidissima	suspension feeding bivalve
Echiurus pallasii	deposit feeding echiurid worm
Phoronis architecta	suspension feeding worm-like lophophorate coelomate

Two species that were present at stations 14-1 and 14-2 but absent in the colonized spoil stations were _Orchomella pinguis_, an amphipod, and _Ptilanthura tenuis_, and isopod.

Fauna introduced with the dredge spoil: Four species from the dredge area were found on the spoil dump. Three of these, a polychaete, Nephtys incisa; a gastropod, Nassarius trivittatus; and a bivalve, Mulina lateralis occur in the natural fauna of Rhode Island Sound. The individuals of these species which reach the spoil surface after dumping can be expected to become permanent members of the spoil dump population. Streblospio benedicti, a small polychaete abundant in the dredge area was also found in the dump site. This species is adapted for brackish water and feeds on organic deposits on the sediment surface. It probably does not survive long at the dump site where it would find little food in a non-depositional environment even if it could adjust to full salinity.

There seems to be little possibility that the transplantation of adult benthic invertebrates from the spoil source areas will establish any new permanent populations offshore. The planktonic larvae of these same species would have colonized the area previously if the environment had been suitable.

Colonization of the spoil: When a new sediment surface is formed by spoil dumping, it is available for colonization by the adults of motile species and by the planktonic larvae of both motile and sessile species. The order in which species appear on the spoil is a function of their motility and the extent to which they are attracted to, and can survive on, the new sediment surface.

Colonization may involve changes in species representation through time as the spoil is modified by activities of the animals. This primary succession is well described in terrestrial plants. When bare ground is exposed a pioneer stage of quick growing plants develops. This is followed by a series of other plant groups, each modifying the environment in a way that makes it possible for the next group to become established. The final community is called the climax and is correlated with climate. Some of the characteristics of a climax community on land are permanence, high standing crop, and high diversity of species.

There have been few opportunities to study succession in marine bottom communities. Shelford et al. (1935) suggested that a soft bottom community gave rise to a hard bottom community in Puget Sound, Washington. Reish (1961), however, found no evidence of succession in the colonization of a new harbor in Southern California. Carriker (1967) reviewed the ways in which benthic organisms modify their environment. He concluded that these modifications would made the habitat suitable for new species and that succession would take place.

An important aspect in the colonization of new seabottom is the ability of many benthic species to select the surface on which they settle. Wilson (1958) reviewed the factors mediating settling. These included texture of the surface, particle size, and the presence of substances which induce metamorphosis or have olfactory attraction. The presence of adults of the same species was frequently an attractive factor. A fresh spoil surface would differ markedly from the natural bottom in the quality and quantity of each of these factors. Some species might not settle until the sediment has been modified by exposure to seawater, addition of natural sediment, or by the presence of less selective colonizers.

It is worthwhile to review some of the studies that have been made of the repopulation of marine and estuarine sediments as a basis for the interpretation of the results of this study.

In spoil disposal operations that were studied in the upper Chesapeake Bay by Pfitzenmeyer (1970) and the lower Chesapeake Bay by Stone (1963), the spoil was dumped close to where it was dredged and was distinguishable from natural sediments only by bulk properties. The natural populations in both areas were characterized by large seasonal variations in numbers. Recruitment of juveniles and mortality were both high. This made the interpretation of repopulation of the spoil and the dredged channels difficult. In both areas repopulation was by the same species that had occupied the area before the dredging, and was accomplished in 1 1/2 years. In the lower Chesapeake Bay N. incisa and Retusa canaliculata, a small carnivorous gastropod, were early colonizing species on the spoil banks. Errant polychaetes were colonizers of the dredged channel. Bivalve mollusks were absent from both environments for a longer period.

In a study of a newly dredged harbor, Reise (1961) found that the clay bottom was colonized by deposit feeding polychaetes of the genera Lumbrineris, Prionospio, Spiophanes, Tharyx, Capitita, and Dorvillea. There was no evidence of a sequence of species colonizing the area. The principal species were dominant during the entire 3-year period of the study.

A report by Howell and Shelton (1970) is of particular interest. They studied the effect of china clay waste deposited on a formerly sand and gravel bottom of a bay in England. Close to the discharge area the clay was deposited at a high rate and the bottom was nearly sterile. Where the rate of deposition was less, a rich community developed consisting of species specialized for soft bottoms. A burrowing sea urchin and a brittle star were dominant species. Other important species included Nephtys sp., a sedentary polychaete (Melinna sp.), three small bivalves (Tellina sp., Abra alba, and Cultellus sp.), and a holothurian (Labidoplax sp.). This fauna was more productive than the original fauna. The small bivalves and sedentary polychaetes were eaten by commercially important fish.

A preliminary report was made by the Sandy Hook Marine Laboratory (1970) on the effect of sewage sludge and dredge spoil dumping in New York Bight. The spoil was highly polluted. Little or no macrofauna was found on either the sludge or spoil. Marginally polluted areas were identified which had a characteristic fauna dominated by Cerianthus americanus. A hypothesis was made that the impervious tube which this species occupies confers protection from toxic materials in the environment. Other members of this fauna are:

Yoldia limatula	deposit feeding bivalve
Nucula proxima	deposit feeding bivalve
Nephtys incisa	deposit feeding polychaete
Prionospio malmgreni	deposit feeding polychaete
flabelligerid sp.	deposit feeding polychaete
lumbrinerid sp.	deposit feeding polychaete
maldanid sp.	deposit feeding polychaete

The abundance of these deposit feeders was explained on the basis of high organic matter (10% of dry weight in several samples) and fine grain size. Unciola irrorata was the only amphipod species found on the impoverished portion of the dumping grounds. The marginally polluted areas also had few amphipod species. The hypothesis was made that amphipods as a group were sensitive to the effects of pollution.

The pattern of colonization of the spoil in Rhode Island Sound had elements in common with those found in the studies reviewed. Nephtys incisa was a colonizer in several of the areas. This active species is found in muddy bottoms over a wide range of salinities and is able to live in moderately polluted environments. It was found in most of the spoil samples taken in the present study. The presence of small individuals (5-10 mm) indicated that the spoil was attractive to settling larvae.

Several polychaete species were found on the spoil which belonged to groups colonizing muddy bottoms in other areas. These included Prionospio malmgreni, Cymenella torquata (Maldanidae), and Pherusa affinis (Flabelligeridae), Tharyx acutus, and Ninoe nigripes (Lumbrineridae).

Colonizing species which were members of the sandy silt fauna of Rhode Island Sound sampled at station 9 included the polychaetes C. torquata, P. affinis, and N. nigripes; a bivalve, Pitar morrhuana, and a small sabellarid polychaete. The relationship between this fauna and the spoil fauna was slight, however. Dominant soft bottom species which were rare or absent on the spoil included Nucula spp., Cerianthus americanus, Edwarsia elegans, Periploma papyratium, and Bostrichobranchus pilularis.

Several species of small polychaetes which were present in the natural amphipod colonies were abundant on the spoil; these include P. malmgreni and T. acutus, mentioned previously, and Eteone longa, Pholoe minuta, Heteromastus filiformis, and Harmothoe extenuata. The colonization of the spoil by these rather than by silty bottom species may be due to the abundance of their larvae in the water over the spoil site. It is possible, however, that these polychaetes show less substrate selection and are less specialized and faster growing than soft bottom species and thus are better adapted to colonize the new bottom.

Ampelisca agassizi colonies were found only near the edge of the spoil dump. Their density at stations 11-1 and 11-3 was about 1/4 that in the natural community at stations 14-1 and 14-2. This indicated that the spoil is an acceptable substrate for juvenile amphipods, but that several years might be necessary before a dense colony is established. A. agassizi extracts its food directly from the water and may be much less sensitive to sediment quality than most deposit feeders.

Mills (1967a, 1969) described the biology of *A. abdita* on tidal flats. Dense colonies of this species produced a mat of tubes and fine material which they had removed from the water. These areas were unstable and often eroded away in patches. The juveniles colonized bare sediment where there was less competition from adults and less chance of a "wash out". *A. abdita* was described as a "fugitive species" adapted to frequent changes of the area occupied. *A. abdita* communities were described as "dynamically instable" with little species constancy or biological accommodation.

There is no way of assessing the permanence of *A. agassizi* colonies on the dump site at the present time. An initial hypothesis is made, however, that these offshore populations are more permanent than those of the intertidal region. Evidence of stable colonies might be found in adaptation of the juveniles of offshore species for settling among adults.

Leptocheirus pinguis, a large suspension feeding amphipod, differs from the ampeliscids in that its tubes are temporary and it frequently moves across the bottom. *L. pinguis* of several age groups were abundant at station 11. It is possible that this species selects bottom areas where a mat of permanent tubes is not well developed.

Only a few species which were abundant in the *A. agassizi* community were rare or absent at station 11. These include *Ptilanthura tenuis*, an isopod; *Orchomella pinguis* and *Phoxocephalus holbolli*, amphipods; and *Diastylis quadrispinosa*, a cumacid. These may be specialized for existence in the fully developed amphipod colony.

In the discussion of the sedimentary geology of the spoil a prediction is made that the spoil would develop a stable surface with a grain size distribution near that found on the area before dumping began. If this takes place, the bare sediment surface will become less attractive to deposit feeders. These will be found mainly in the microenvironment between and beneath amphipod tubes.

The general pattern of colonization of the spoil seemed to be an addition of species in the order of their powers of dispersal. According to this view motile adults move onto the spoil soon after it is dumped, and within a year colonization takes place by abundant, non-selective larvae of opportunistic species. There are indications that colonization by more selective or rarer larvae of longer lived species adapted for silty bottoms will be cut short by Ampelisca dominance. A series of yearly surveys following cessation of dumping would show the progress of this colonization.

Species diversity and patterns of abundance: The number of species and the relative abundance of each species are important community characteristics. A community with a large number of species can be assumed to have occupied a stable environment over a long time (Sanders, 1969; Slobodkin and Sanders, 1969). Measures of diversity based on information theory take into account both species richness and the evenness or equitability of the distribution of individuals among species (Patten, 1962). Stable environments are expected to have not only a large number of species, but also many moderately abundant species. Each species would be a specialist in the efficient use of some resource. The degree of biological accommodation would be high. In environments where animals are stressed by natural variation in temperature or salinity or by pollutants, the number of species is low but the dominant species are superabundant. These "opportunist" species are controlled by the physical elements of the environment rather than the biological elements.

Diversity may be expressed as the degree of uncertainty attached to the specific identity of any randomly selected individual (Pielou, 1966a).

In a sample with many abundant species this uncertainty is large and the diversity of the sample is large. Pielou (1966a, 1966b) indicated that Brillouin's formula for the information in bits per individual, $H = (1/N)(\log N! - \sum_{1}^{s} N_i!)$, is the appropriate index for describing a single collection. Pfitenmeyer (1970) used this index in a study of Chesapeake Bay spoil dumping. Several benthic ecologists (Phelps, 1964; Boesch, 1970; Lie, 1968) have used the Shannon and Weaver formula which gives an estimate of H for a randomly sampled population: $H' = \sum_{1}^{s} P_i \log P_i$, where P_i is the percent composition of each species in the sample. H' was used in this study to facilitate comparison with the three studies mentioned.

Boesch (1970) gives a summary of the value of macrobenthic diversity indexes calculated for samples from a variety of sources. H' values of 4-5 are found on the outer continental shelf and slope and in stable, cool Puget Sound. H' values near 3 seem typical of shallow shelf and unpolluted estuaries. H' values between 1 and 2 are found in the brackish parts of estuaries and in polluted areas.

Even the most stable and diverse communities do not have species abundances approaching equality. There are always a few dominant species and a greater number of less abundant species. There has been speculation that the distribution of individuals among species in an undisturbed community conforms to certain statistical distributions. MacArthur (1960) suggested that a Whitworth distribution will result from division of resources among species with nonoverlaping requirements. Preston (1962) showed that this expectation seemed to fit collections of territorial species, but that samples from a variety of environments have a distribution with common species too common and rare ones too rare. Figures 32-42 show that the assemblages sampled in this study which have grouped by sediment type

Figures 32-48 Patterns of species abundance in 1/10 M^2 samples.

Percent composition of each species is plotted against rank of abundance.

n indiv = number of individuals in the sample

n sps = number of species in the sample

H' = bits/individual, an index of the diversity of the sample

* indicates values of n indiv, n sps, and H' when <u>Ampelisca agassizi</u> was removed from the records.

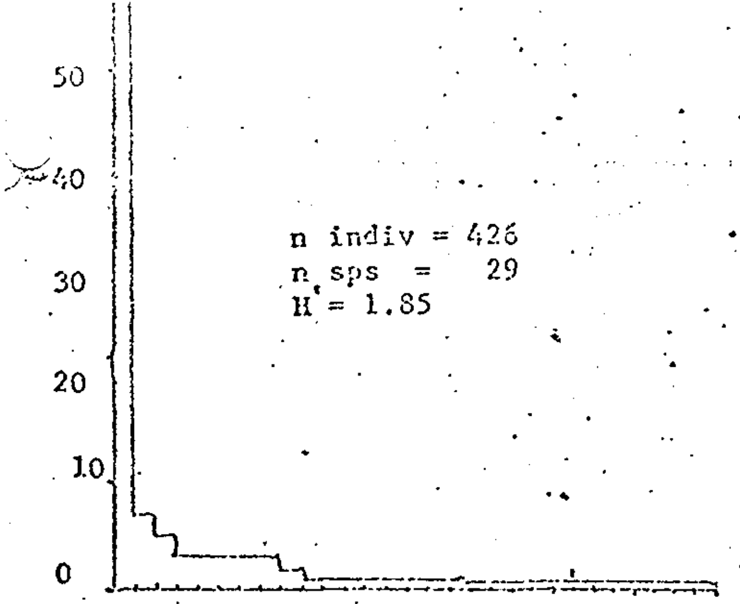


Fig. 32 Station 7-1

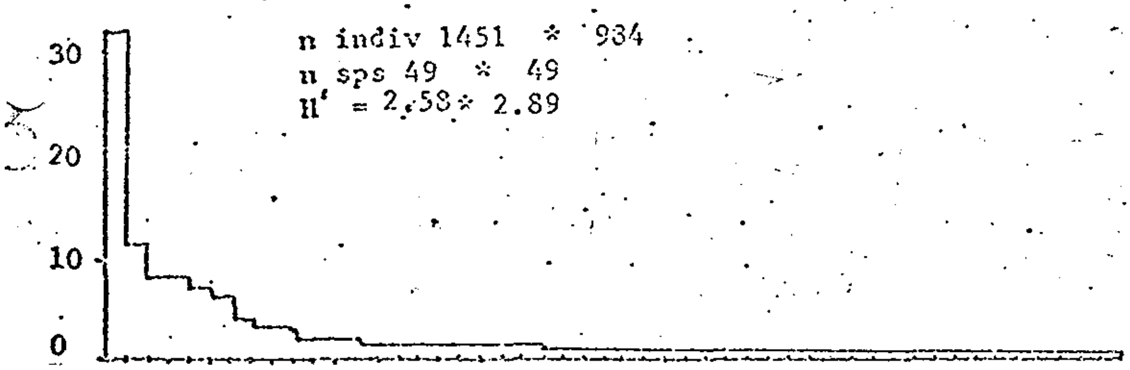


Fig. 33 Station 7-3

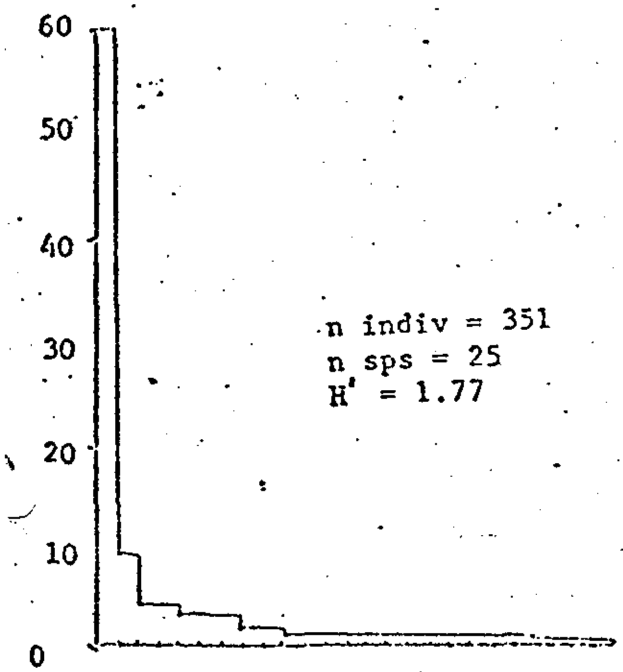


Fig. [illegible] Station 7-[illegible]

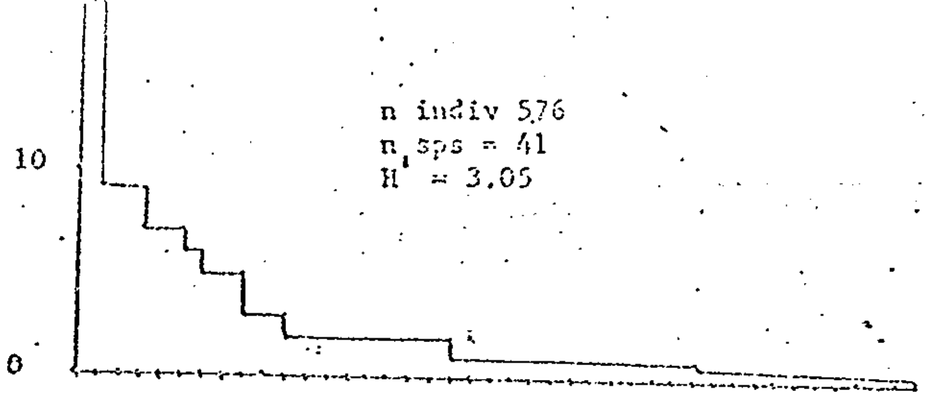


Fig. 35 Station 9-1

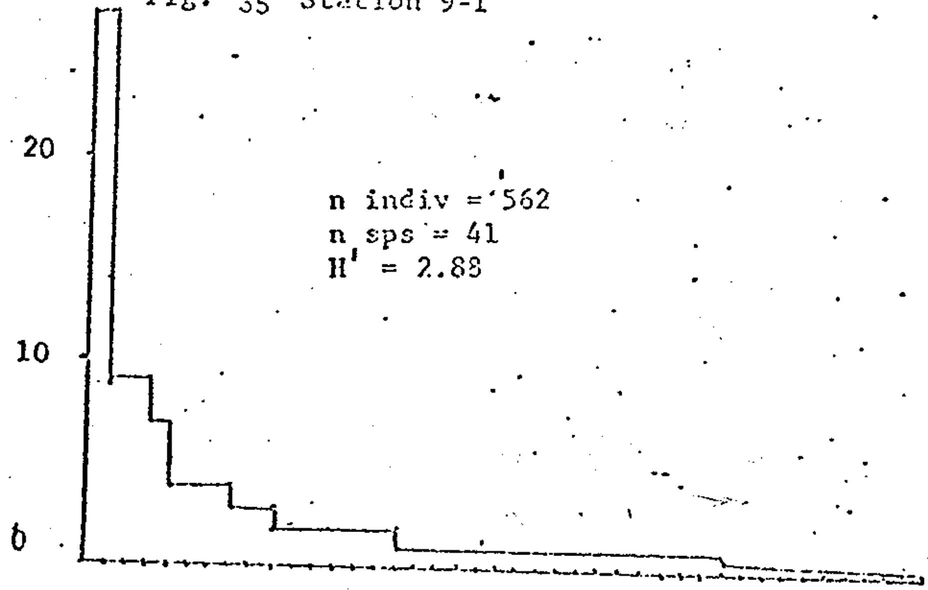


Fig. 36 Station 9-2

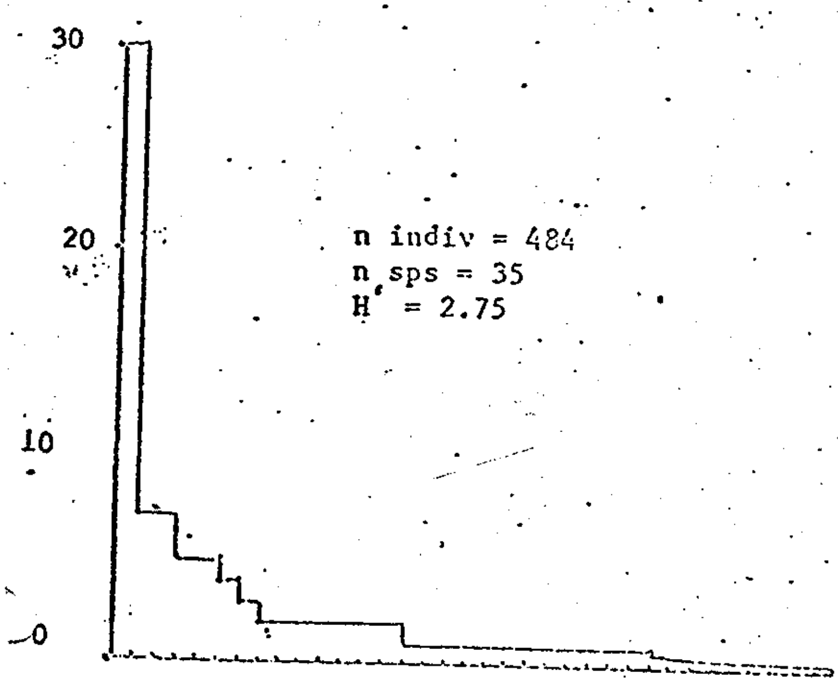


Fig. 37 Station 9-3

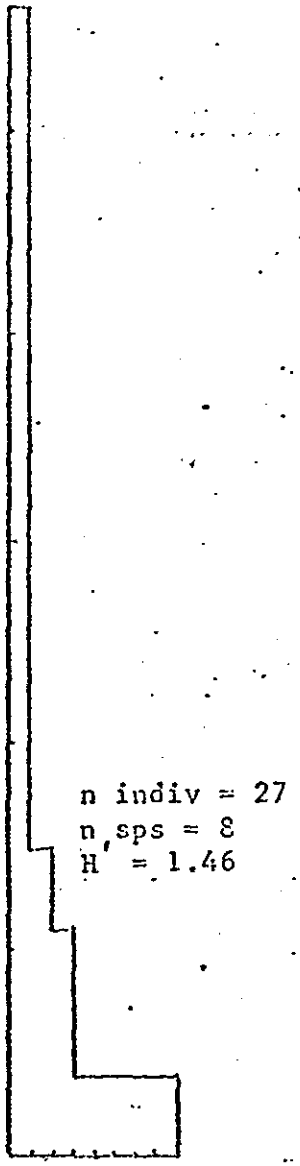


Fig. 38 Station 8-1

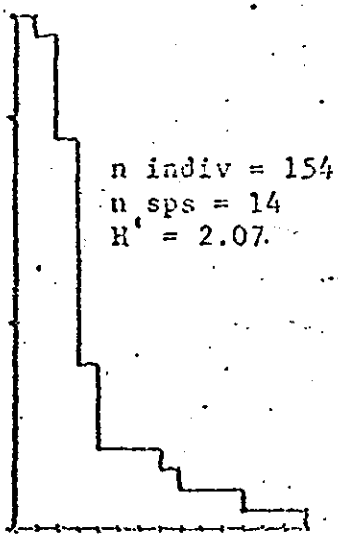


Fig. 39 Station 8-2

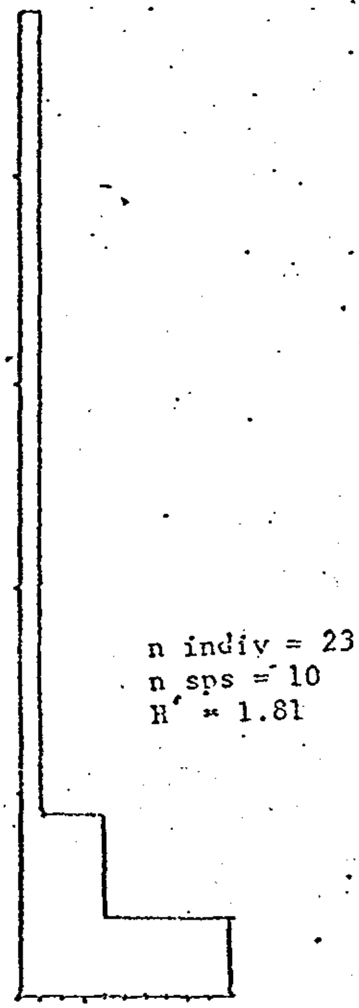
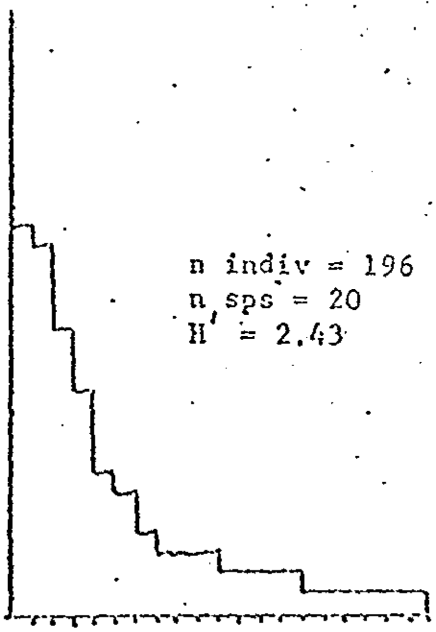


Fig. 40 Station 8-2



ig. 41 Station 10-1

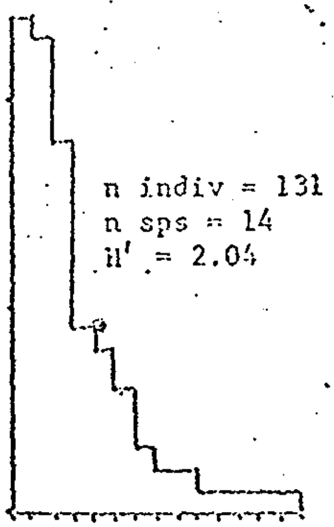


Fig. 42 Station 10-2

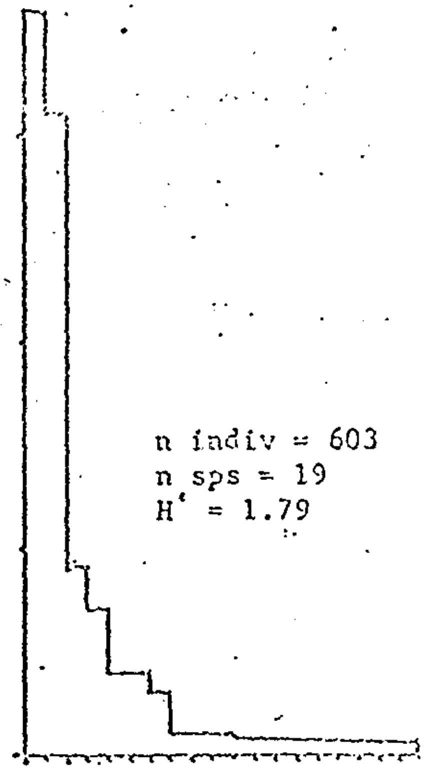
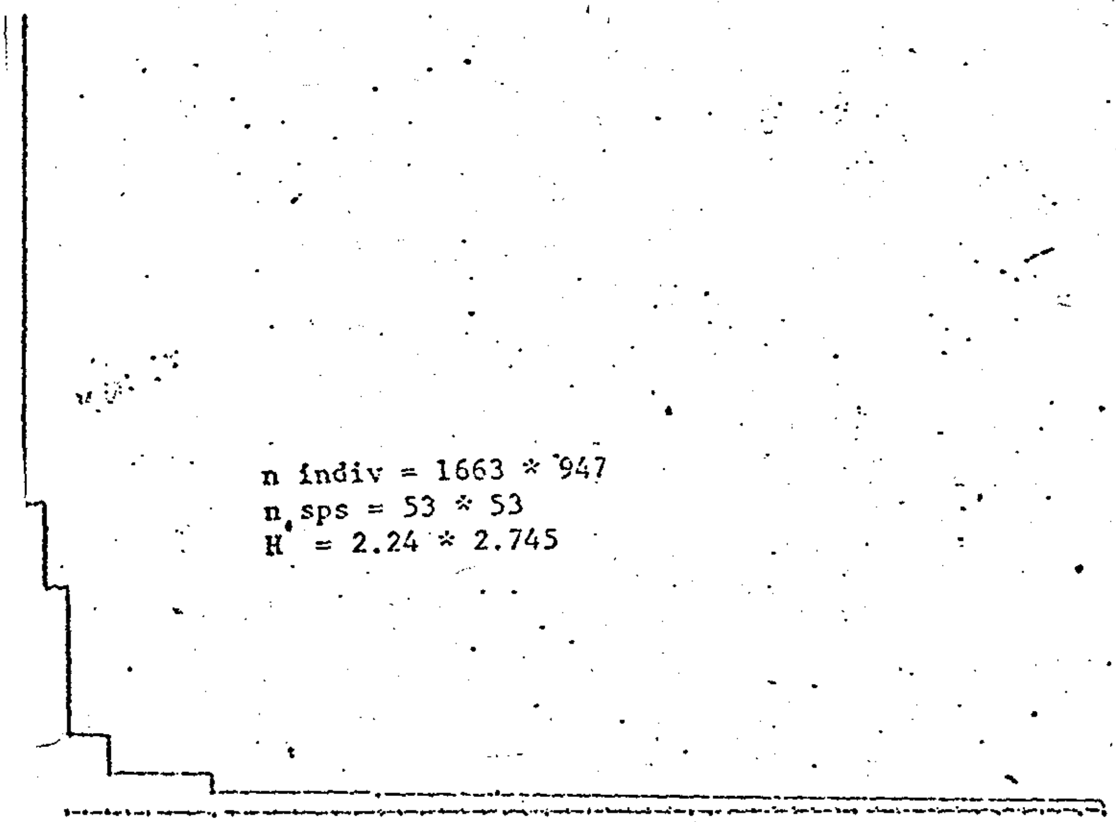


Fig. 43 Station 10-3



ig. 44 Station 11-1

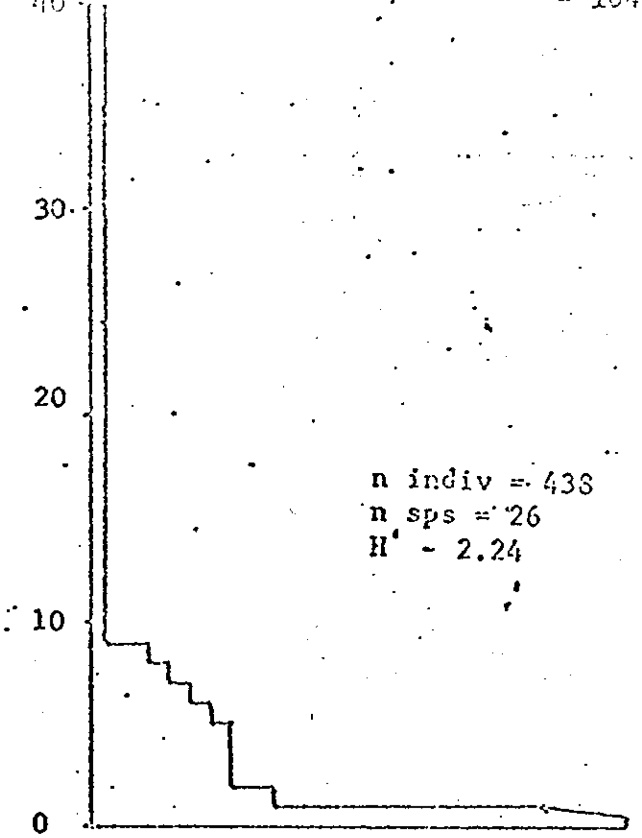


Fig. 45 Station 11-2

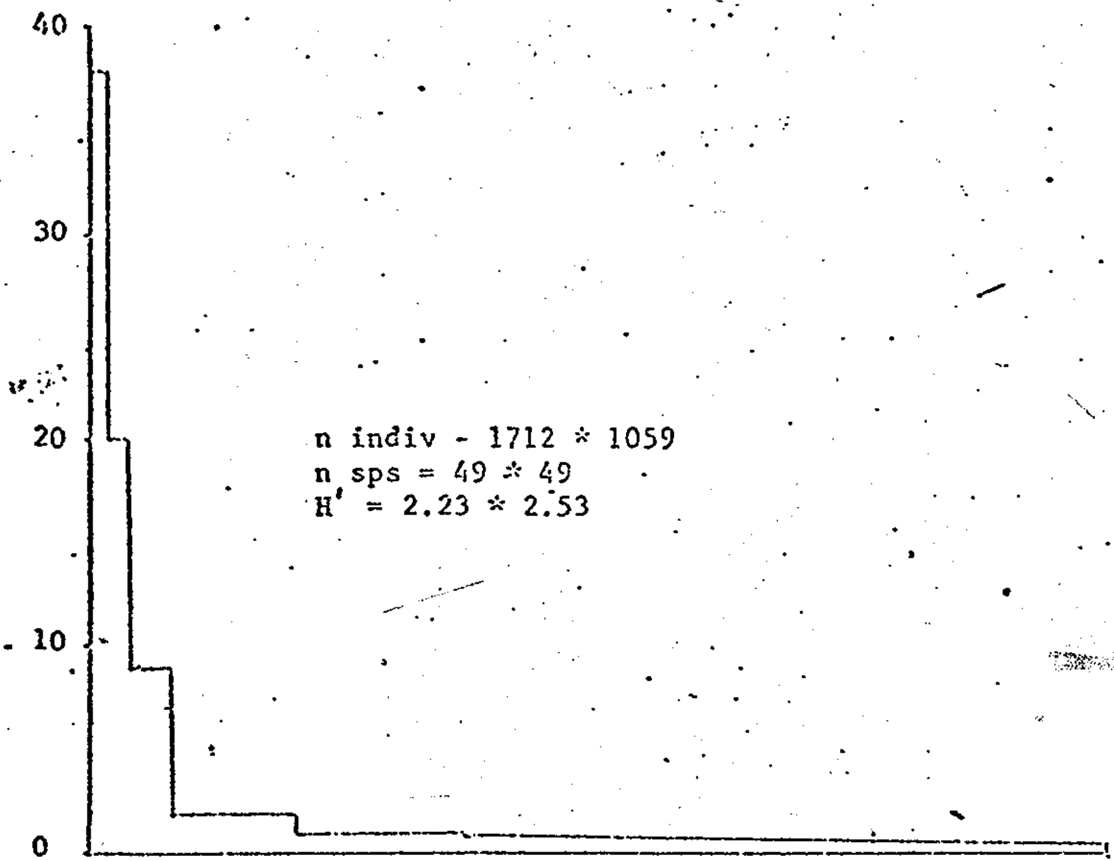


Fig. 46 Station 11-3

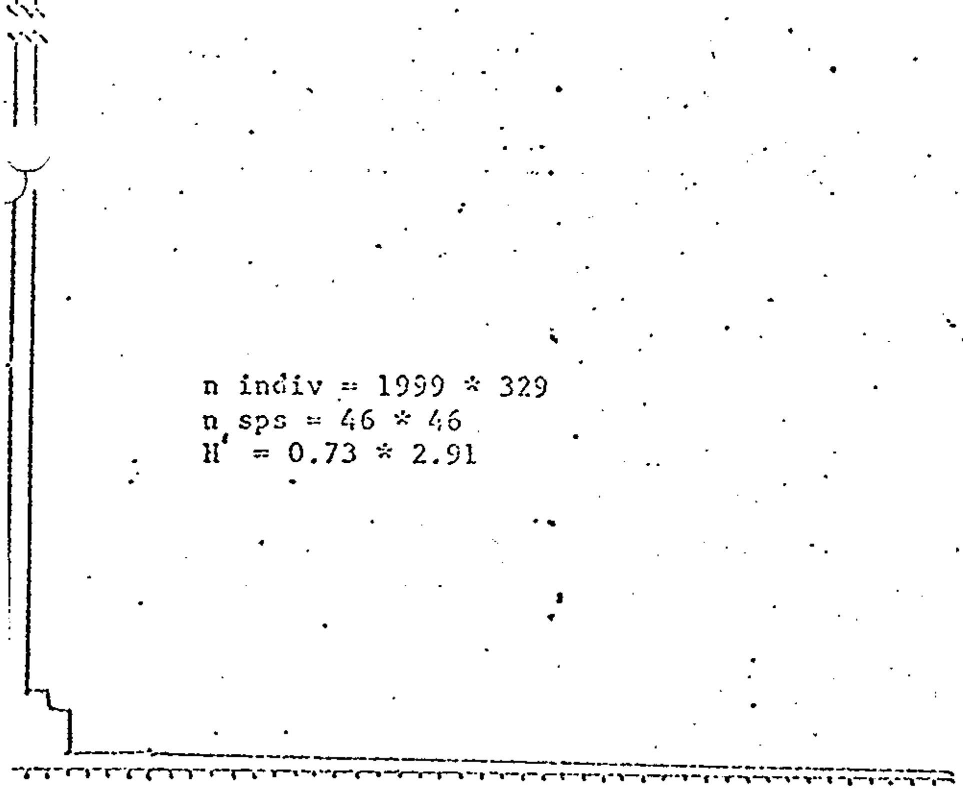
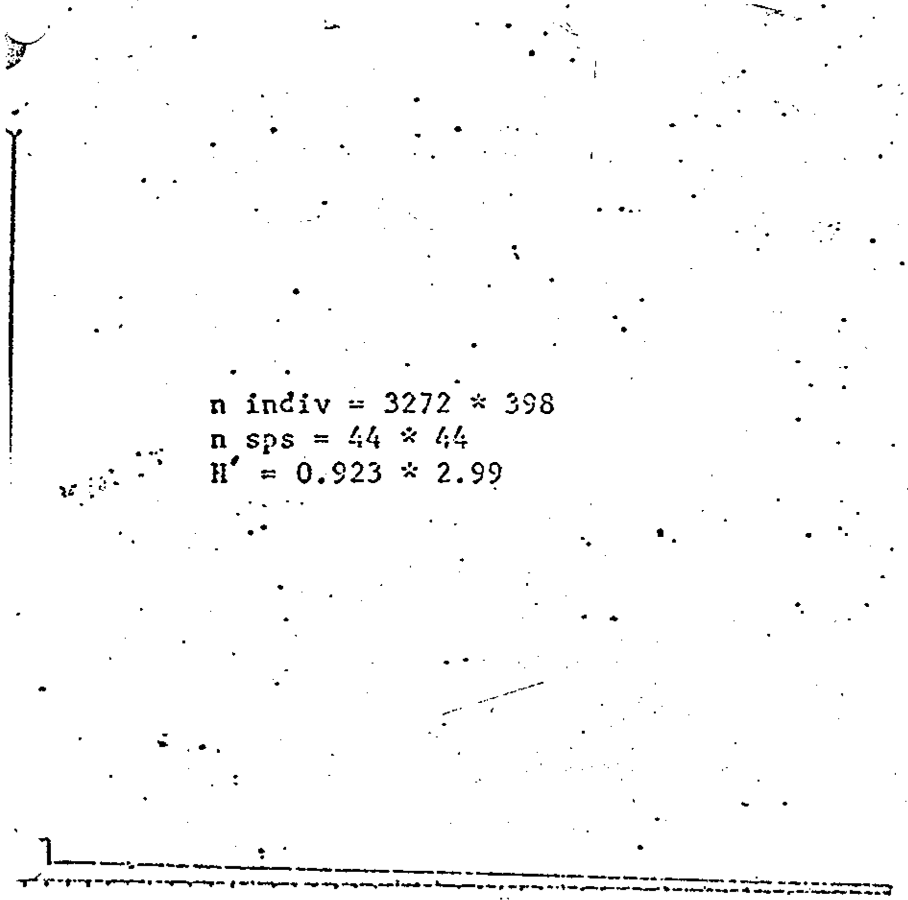


Fig. 47 Station 14-2



ig. 48 Station 14-1

and similarity of fauna also had characteristic patterns of species diversity and species abundance.

Samples 7-1 and 7-2 from clean sand had relatively few species (21, 25) and were dominated by a single amphipod, *Byblis serrata*. The diversity index values were low, 1.85 and 1.77.

Samples 7-3, 14-1, and 14-2 sand colonized by amphipod colonies had many species (49, 46, 44). They differed in that 7-3 has several abundant species and a moderate diversity value of 2.58, while 14-1 and 14-2 were dominated by a single species, *Ampelisca agassizi*, and had very low density index values of 0.73 and 0.92.

Diversity indexes are usually used to compare groups of organisms with overlaping requirements. Benthic animals, for instance, are considered separately from planktonic animals. The difference in the food sources of suspension feeding and detritus feeding benthic animals may be so great that they should be considered as making up separate communities. When the dominant filter feeding amphipod was removed from the records of samples 14-1 and 14-2 and the diversity indexes recalculated, they increased to 2.91 and 2.99, indicating that the deposit feeding sub-dominants are relatively evenly distributed and possibly well organized.

Samples 9-1, 9-2, and 9-3 from a sandy silt bottom had moderate numbers of species (41, 41, 35) and high equitability giving high diversity values of 3.05, 2.83 and 2.75. Sample 9-1 has an abundance pattern close to the Whitworth distribution. Samples 9-2 and 9-3, like most of the samples in this study, had patterns varying from the Whitworth distribution in that abundant species were too abundant and rare species too rare.

Samples 11-1 and 11-3 from colonized dredge spoil had large populaions of *A. agassizi* and a high species total (53, 49). The diversity index values were moderate (2.24, 2.23) and increased when *A. agassizi* was removed (2.74, 2.53).

Samples 11-2, 10-1, 10-2 and 10-3 on less well colonized spoil had a reduced number of species (26, 20, 14, 19). Diversity index values were moderate (2.24, 2.43, 2.04, 1.79) because of the evenness of abundances of the species. These samples do not represent functional communities. The species found in them are only samples from other communities; they had been deposited with the spoil, had entered as motile adults, or had settled as larvae or juveniles.

These analyses showed that differences in species richness and diversity were not correlated in a simple way with disturbance of the bottom by spoil dumping. The controlling effects of the presence or absence of amphipod colonies on these indexes detracted from their usefulness. It seems likely that deposit feeders are more sensitive to changes in sediment quality than are suspension feeders. These groups should be considered separately in future analyses.

Benthic invertebrates eaten by fish: The area of seabottom directly affected by spoil is small when compared with the total area of Rhode Island Sound of over 500 square miles. It is nevertheless important to consider the recolonization of this area in terms of fish attraction and productivity. The change in fisheries potential of this area can help in the assessment of the effects of dumping or dredging in other offshore areas.

Unfortunately many of the species that are important as food of bottom fish are large and motile, and are not samples by a 1/10 M^2 grab. These include crabs (Cancer spp.) and shrimp (Crangon septemspinosus) which are important food items of cod, hake and eel pout. These motile species can be expected to respond to sediment quality and the presence their prey.

Smith (1950) analysed the food of the dominant fishes in Block Island

Sound. The bottom in this area was sand and sandy-silt and so was representative of the bottom around the dump site. The fishes feeding on bottom invertebrates in Block Island Sound included winter flounder (*Pseudopleuronectes americanus*), skate species, sculpin, eelpout, and sea-robin. The annual consumption of bottom invertebrates by weight consisted of 90% crustacea, 60% amphipod crustacea, and 46% *Leptocheirus pinguis*. Another amphipod, *Unciola irrorata* made up 8% of the food consumed annually. The recolonization of the spoil area by amphipods, and in particular by the species *L. pinguis* and *U. irrorata*, would provide food for these fishes.

Richards (1963) studied the food of fishes in a muddy and a sandy area of Long Island Sound. She found that winter flounder ate at least 73 different species of benthic invertebrates. On muddy bottoms polychaetes made up a large proportion of their diet. The only other fish that was found to eat a high proportion of polychaetes was scup (*Stenotomus chrysops*).

The stomach contents of flounders caught on muddy bottom west of the dump site were examined. The major food items found were the polychaetes *Pherusa affinis*, *Glycera* sp., and *Nephtys incisa* and the anemone-like *Cerianthus americanus*. It is concluded that if a muddy bottom fauna were to develop on the spoil, flounder and scup would be best able to take advantage of it. Flounders appear to feed on the largest available polychaetes and amphipods. Large amphipods and large *N. incisa* are already found on the edges of the spoil area, but it may be some time before other polychaetes or C. americanus can colonize the spoil and grow to full size.

Summary

1) A small number of pollution resistant benthic species were found in Providence Harbor. Although low oxygen seemed to be the major stress, toxic substances are probably also present in this area.

2) Over thirty benthic species were found in the lower Providence River. These indicated a relatively low level of pollution in that part of the spoil source area.

3) Several species were found on the spoil dump which had been transported from the dredge area. The only abundant transported species which seemed well adapted for Rhode Island Sound conditions was *Nephtys incisa*, a polychaete occurring there naturally.

4) The natural faunal assemblage on sandy sediments in the spoil dump area was dominated by *Ampelisca agassizi*, a tube building amphipod crustacean. Dense mats of *Ampelisca* tubes determined sediment quality and provided a habitat occupied by subdominant species.

5) Much of the spoil was recently dumped and had few animals on it. However, some surfaces which had been exposed to colonization for between one and three years yielded large numbers of species (up to 53 per 1/10 M^2 sample). The presence of these animals indicated that these spoil surfaces lacked gross toxic or repellent properties.

6) Although the spoil was generally silty, only a few colonizing species were recognized as being members of the offshore silt bottom assemblage. Lack of information on the presence of the larvae of these species in the overlying water, made it difficult to ascribe this absence to sediment properties, however.

7) Most of the species colonizing the spoil were members of the surrounding sand bottom assemblage. Several species of deposit feeding polychaetes and an amphipod crustacean, *Leptocheirus pinguis*, were found in greater abundance on the spoil than in their natural habitat.

8) *A. agassizi* was found on some spoil areas indicating that colonization was independent of the quality of underlying sediment where the hydrographic regime is suitable. It seemed likely that this species would eventually dominate the spoil as it did the surrounding area. It was not possible to estimate the time which would be necessary for the establishment of this dominance.

9) Although the faunal assemblages sampled in this study had characteristic diversity index values, these could not be simply interpreted. Some spoil samples had relatively high values indicating little disturbance, while the natural *A. agassizi* assemblage had extremely low values.

10) Several of the species which were abundant on the colonized spoil have been reported to be used as food by commercially important fish.

FISHERIES RESOURCES IN THE DUMP SITE AREA

The establishment of a dredge spoil dumping ground in Rhode Island Sound is an example of the general phenomenon of a shifting zone of exploitation. In the recent past dredge spoil, solid waste, and sewage sludge were dumped into Narragansett Bay. Several state regulatory agencies, responding to the public view that Narragansett Bay should be reserved for food production and recreation, now cooperate to prevent unhealthy and unsightly exploitation of estuarine waters. At the same time that the volume of materials to be disposed of increases, constraints have been placed on open burning on land, quarrying sand and gravel on land, and the use of estuarine waters for power plant cooling. The near shore waters and sea floor are now being used or being considered for use in disposal, incineration, heat discharge, mining, and oil production; all competing with the traditional uses of recreation, navigation, and various types of fishing.

While various federal agencies have limited regulatory powers concerning ocean dumping, fishing, and navigation, none has the power to assign portions of the sea floor for specific uses. This division among users is often a function of who gets there first and who can defend their claim most strongly.

Before any agency can rationally allocate sea floor areas it will be necessary to know the location of all resources presently being utilized and those which may be used in the future. A lack of specific knowledge concerning the location of Rhode Island Sound fishery resources made the choice of a dump site for the Providence River spoil difficult. Local fisherman voiced strong objection to the location of three sites which were used for short periods before the present site was chosen. The first site ("A", Fig. 50) was in the center of an important lobster fishing area while the second and third ("alternate site" Fig. 1 and "C", Fig. 50) were near important trawling areas.

Several contrasting types of commercial fishing are carried on in Rhode Island Sound. Each has its own area and gear and has been affected by spoil dumping to a different degree.

Figure 49 shows the general location of trawling grounds for bottom fish in near shore Rhode Island Sound. Deposits of cobbles and boulders along the paths of former glacial moraines restrict trawlers to well defined areas. A single "short dump" of soft silt in such an area may close it for years: the otter boards or "doors" of the trawls can dig in and anchor the net to the bottom. Inacurate dumping in the channel near the alternate dump site in 1967 caused considerable problems. It is reported that this material is presently either spread out or compacted enough so that gear is no longer caught. One fisherman reported that the spoil was better able to support trawling in the winter than in the summer. This agrees with R.L. McMaster's (1967) observations of sediment compaction and dilatence.

The present dump site is on trawling grounds of secondary importance. The area available for trawling is small and surrounded by patches of rocky bottom. It is, however, one of only two areas available to small day-boats from Newport. Larger boats from Point Judith fish here using rollers to keep the trawl free of the rocky bottom.

During the winter, cod (Gadus callarias), blackback flounder (Pseudopleuronectes americanus), and yellow tail (Limanda ferruginea) are caught on hard bottom to the east of the dump site. Sea herring (Clupea harengus) are caught to the west. Sculpin (Myoxocephalus spp.), eel pout (Macrozoarces americanus), skate (Raja spp.), and goosefish (Lophius americanus) are taken as industrial or "trash fish".

In the spring and summer scup (Stenotomus chrysops) is caught on hard bottom to the northeast while whiting (Merluccius bilinearis), and hake (Urophycis chuss) are caught on soft bottom to the northwest. Butterfish (Poronotus triacanthus) is taken in summer and fall northeast in 90 foot depths.

Though there has been a general lack of butterfish and scup in this area for the last three years, it is not possible to ascribe this to spoil dumping activities. Natural variations in abundance are considered a more plausible explanation. Catches of cod and flounder southeast of the dump site have remained excellent, augmented by large catches of cod in areas where the fish had been attracted by quahog dredging.

Four fish trap areas assigned by the State of Rhode Island are shown on the map. Here expensive fixed nets are set up to catch scup, butterfish, mackerel (Scomber scombrus), cod, and menhaden (Brevoortia tyrannus). This fishery has been extremely poor for the last three years. It can be hypothesized that surface feeding fish like mackerel and menhaden with higher oxygen utilization, more mobility, and more visual acuity than bottom fish would be sensitive to water quality and actively avoid turbid water around the dump site. However, observations made during this study and those of fishermen do not suggest that there is any increase in turbidity in the area outside of the immediate vicinity of the dump site other than immediately after large storms.

It is a fact that fish catchability for bottom trawling is low during post-storm turbidity. Several fishermen interviewed stated that the period of turbidity following storms producing ground swell now lasts a week rather than three days as in pre-dump years. This turbidity is reported to be spread throughout Rhode Island Sound rather than moving one way or another from the dump site. Data on the frequency of storms producing ground swell and on the pattern of winter fishing are necessary to assess the actual losses which might be incurred.

There is a long-line hook and line fishery for cod during the winter and spring this is probably not affected by spoil disposal.

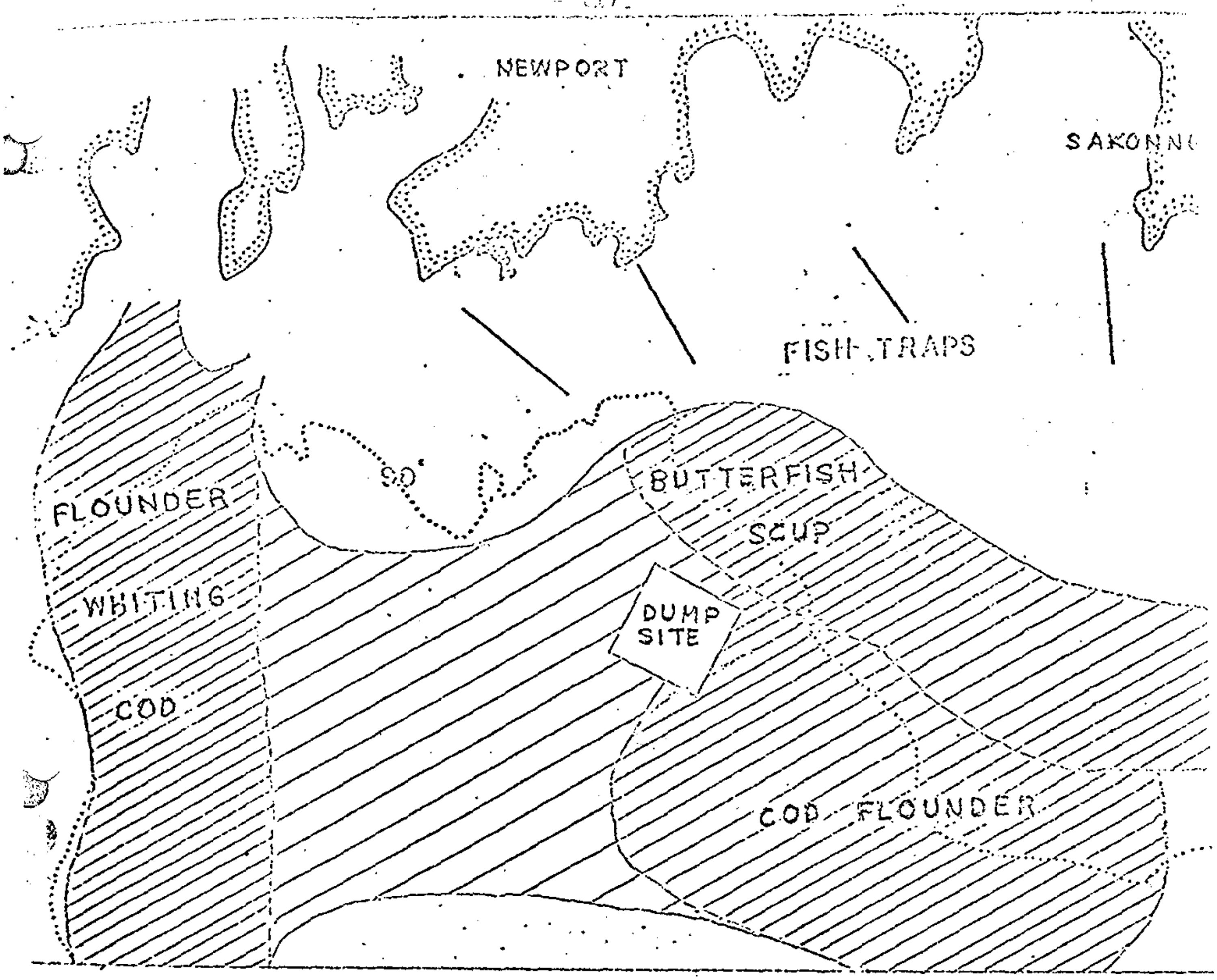
Lobster fishing with strings of pots is carried on throughout this area during the warm months. Large areas on or near rough bottom have high densities of pots. A knowledgeble fisherman who had been lobstering in the dump site area for eight years has continued to fish close to the spoil area. He has placed pots within the dump limits on the south, southeast, and east and has asked the dredging project managers and the tow boat operators to avoid this area if possible. He reported that pots close to the dump zone often come up with a ½ inch layer of grey silt-clay on them, yet may have a good to excellent catch per pot. He suggested that lobsters may be attracted to this soft bottom to bury for the winter. It seems more likely, however, that lobsters which enter this area during natural inshore-offshore movements continue to move across the bottom in search of food, and thus are likely to discover a trap. This fisherman reported that sea bass (Centropristes striatus), a valuable food fish, was caught in pots close to the dump site much more frequently than elsewhere. While a few other lobstermen experimented with fishing close to the spoil, most avoided the area for fear of low or polluted catches and loss of gear by burial or by cutting of buoys by tow lines.

The dump site is located near the center of a discrete patch of mahogany, black or ocean quahogs (Arctica islandica) (Fig. 50). Although the location of this has been known for over twenty years, Arctica was not being utilized at the time that the dump was established. At least four boats were dredging for Arctica in this area during the study period. This area was preferred since the next closest concentrations are 10-12 miles offshore. The boats frequently operated near the boundries of the spoil area.

Dead Arctica have been recovered by these boats at several locations (Fig. 50). In each case spoil sediments were recognized. The animals near the dump site probably had been buried by spoil dumped near the site perimeter and by sediments which were suspended during dumping and flowed beyond the designated disposal area. The dead animals in the area southwest of the dump site were probably buried by spoil dumped in area "A" during the 20 day period that it was used in 1967.

The limited ability of Arctica to move through sediment (Schafer, 1962) may make them particularly vunerable to death by burial. It will be important to determine whether deaths can be caused only by gross burial or by relatively thin layers of transported sediment (1-4 cm) as well.

In conclusion it is clear that there is no such thing as unutilized sea bottom in these inshore waters. Most users of this area agree that future dumping should be on the existing site unless a new site can be established very far offshore. However use of the Rhode Island Sound sea floor for dredge spoil disposal can be accepted only if it is possible to guaranty that there will be no errors in the location of dumping. The effects of resuspension and sedimentation around the dump site are probably small, but a "short dump" in a trawling or dredging area could effectively close it to fishing for years.

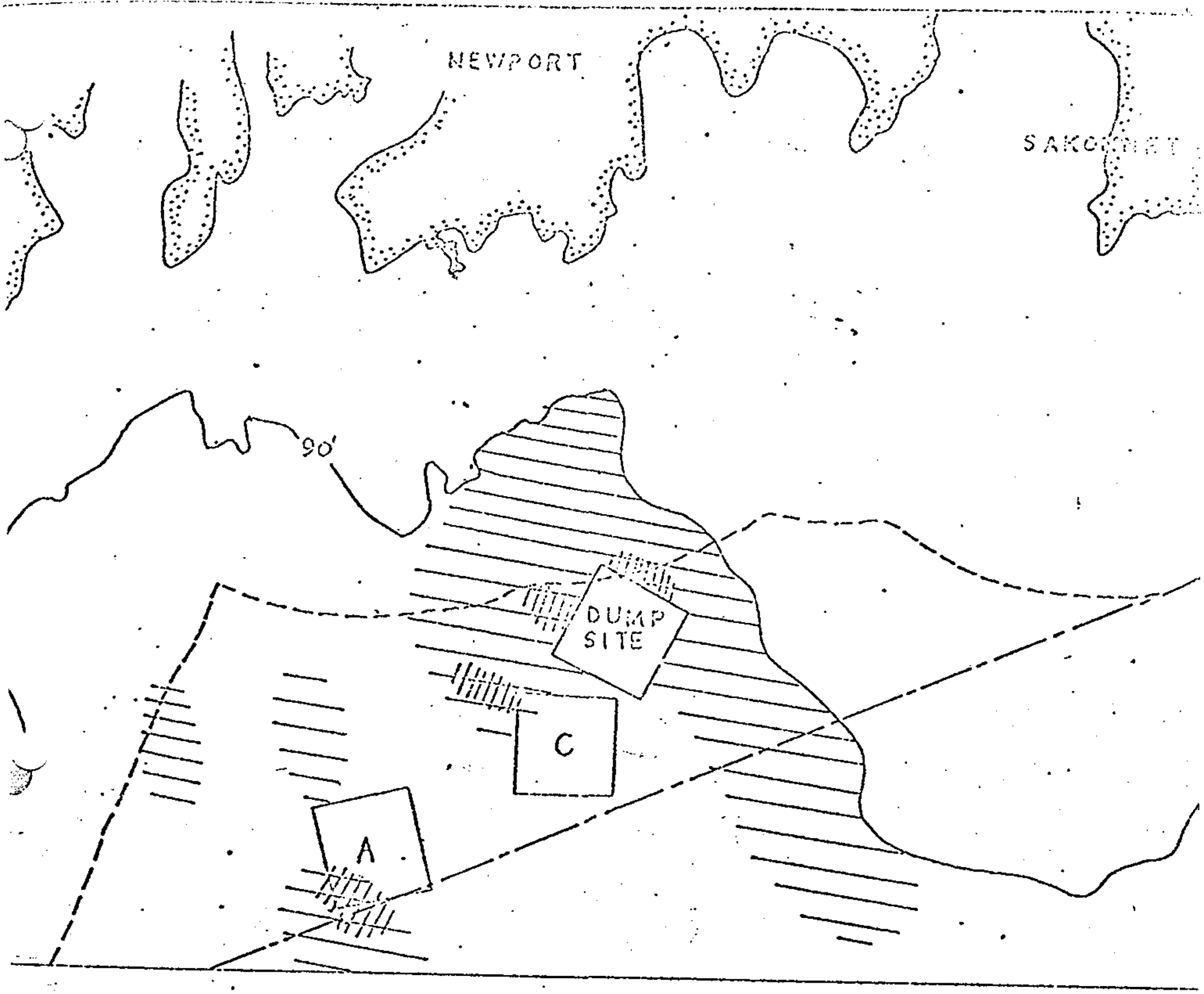


Primary trawling grounds

Secondary trawling grounds

Lobster pots are set throughout this area in the summer except on the west trawling grounds.

Fig. 49 General areas used by various fisheries in the dump site area.



General location of ocean quahog grounds.

Areas from which dead ocean quahogs and dredge spoil have been reported by fishermen.

Present Rhode Island state line.

Rhode Island state line under proposed amendment GL 42-1-1.

A Original contract disposal area used 21 September-10 October, 1967.

C "Navy garbage dump" disposal area used 20 November-3 December, 1967.

Fig. 50 Areas important in the *Arctica* or ocean quahog fishery in Rhode Island Sound.

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Table 1. Visual Description of Frozen Cores From the Test Site Prior to any Treatment. Cores collected July-August 1969.

Station	Size	Color	Other Comments
28	fine sand	olive	uniform
39	fine sand & mud	darker olive	uniform
2	fine sand bottom - mud surface & bottom	black	2 layers
29	fine sand to surface - mud surface	olive & black	2 layers
3	mud	black	uniform
34	mud	black	uniform
38	fine sand bottom - mud surface	olive - black	3 layers - (1) new mud (2) old mud (3) sand
[illegible]5	bottom mud - fine sand intrusion - surface mud	black	3 layers
16A	disturbed sample - bottom shells, sand & mud surface	black	3 layers mixed
37	fine sand bottom - black sand surface	olive - black	
18	fine sand mostly mud bottom - mud surface	black	2 layers
26	mud	black	uniform
19	olive sand bottom - black sand surface		2 layers
21	fine sand	olive	uniform
17	fine sand bottom - mud surface	olive - black	2 layers
[illegible]	fine sand	olive	uniform
35	mud	black	uniform

able 1. Con't.

tion	Size	Color	Other Comments
1	fine sand bottom - mud surface	mostly black	2 layers
16	mostly fine sand bottom - mud surface layer		2 layers
20	fine sand	olive	uniform
21	fine sand	olive	uniform
12	fine sand	olive	uniform
11	fine sand bottom - mud surface	olive - black	2 layers
9	fine sand with organics	olive -- black	uniform
13	mixed gravel, sand, mud		
24	fine sand	olive	uniform
25	fine sand	olive	uniform
22	fine sand	olive	uniform
8	fine sand	olive	uniform
23	fine sand	olive	uniform
14	mixture shells, sand, mud		
27	coarse sand - thin layer surface mud		
7	mud bottom - sand-mud surface		
5	mud	black	uniform
1	fine sand	olive	uniform
[illegible]	fine sand	olive	uniform
[illegible]	fine sand - very fine sand surface	olive	

Table 1. Con't.

Station			
5	fine sand	olive	uniform
4	mud	black	uniform
33	fine sand bottom - coarse sand surface		2 layers
30	fine sand		uniform

ble 2. The results of mechanical and chemical analyses performed on the amples taken during August, 1969 from the test site and its vicinity.

Mechanical Analyses, Sediments*
July - August 1969

Diameter mm (%)

Station No.	2 - 1.0	1 - 0.5	0.5 - 0.25	0.25 - 0.1	0.1 - .05	<.05
1	1.8	21.6	15.5	37.4	21.5	02.1
2	2.5	12.7	20.6	41.7	18.8	03.7
3	01.6	07.2	07.5	34.0	42.8	06.9
4	04.2	09.7	10.9	39.3	28.4	07.5
5	03.1	22.4	26.4	37.4	08.1	02.6
6	24.1	27.3	12.9	14.4	06.9	14.2
7	12.8	08.2	08.2	52.7	17.2	00.9
8	04.0	14.9	13.5	54.4	17.6	01.7
9	00.5	00.0	07.8	74.8	15.8	01.0
10	00.4	8.8	17.1	59.9	08.1	05.6
11						
12	01.0	6.7	12.0	60.2	18.7	0.8
13						
14						
15	06.2	17.9	09.3	30.7	18.6	17.1
16	01.2	04.0	01.3	53.2	12.0	06.9
17	05.9	15.7	12.0	33.3	26.9	06.1
[illegible]	02.7	12.6	13.1	44.5	21.0	08.[illegible]
[illegible]	02.1	07.8	10.9	47.2	18.4	13.8
0	00.4	08.2	11.8	67.4	10.9	01.7

Table 2. Con't.

Station No.	Diameter mm (%) 2 - 1.0	1 - 0.5	0.5 - 0.25	0.25 - 0.1	0.1 - .05	<.05
23	00.8	5.1	12.1	62.2	18.5	01.2
24						
25	1.6	9.7	15.6	55.1	16.5	1.5
26	9.6	24.4	11.5	23.2	20.9	10.4
27						
28	0.5	4.8	27.2	46.6	16.4	4.4
29	10.7	6.9	5.1	56.5	17.7	3.1
30	0	1.3	5.7	67.7	20.2	5.0
31	0	4.0	3.4	77.5	10.4	4.7
32	0	8.6	23.4	56.7	8.0	3.3
33	3.3	8.4	7.9	57.6	16.3	6.7
34	2.2	21.4	8.8	22.7	28.2	15.9
35	1.8	1.8	1.1	16.9	35.9	42.5
36	0	1.3	20.1	20.1	24.6	39.6
37	2.9	13.7	9.0	43.6	25.0	5.9
38	0	4.2	3.6	66.2	21.1	4.8
39	11.0	5.8	5.2	60.9	22.9	4.3
40	0	1.8	6.8	69.2	17.4	4.7
41						

* USDA Classification

2 - 1 mm - very coarse sand
1 - 0.50 - coarse sand
0.5 - 0.25 - medium sand
0.25 - 0.10 - fine sand
0.10 - 0.05 - very fine sand
less than 0.05 - silts and clay (by difference)

Table 2 Con't. Core Length and Chemical Analyses

Station No.	Core Length Inches	Dry Wt. Gms.	>2 mm. %.	pH	C %	N %	Hexane extr. %
1	7.0	115	08	7.4	2.1	.103	
2	9.0	175	05	7.9	1.7	.143	0.12
3	6.8	105	01	7.9	3.3	.152	
4	7.5	115	01	7.6	4.1	.170	
5	4.0	085	01	7.4	2.1	.093	
6	6.0	031	67	7.5	3.9	.165	
7	9.3	275	01	7.7	2.1	.063	
8	5.8	145	07	7.4	2.2	.072	
9	6.0	165	04	7.6	1.7	.051	0.08
10	6.3	205	05	7.4	0.6	.033	
11	2.5	66	01	7.6	0.6	.041	
12	6.8	210	03	7.9	0.7	.043	
13	4.3	035	04	7.7	6.6	.153	
14	3.5	054	01	7.8	2.7	.086	
15	5.8	100	01	7.5	4.0	.113	0.01
16	7.0	195	05	7.2	1.7	.063	
17	9.0	175	03	7.2	3.8	.139	
18	5.5	076	01	7.9	4.8	.182	
19	4.5	120	05	7.9	2.6	.087	0.01
20	4.5	116	00	7.7	6.4	.038	0.20, 0.12
21	4.3	120	03	7.6	0.8	.042	
22	4.8	090	01	7.7	0.6	.041	
23	6.8	210	01	7.9	1.0	.046	
24	3.5	085	04	7.5	0.8	.046	
25	7.8	240	04	7.4	1.0	.050	

ble 2 Con't.

Station No.	Core Length Inches	Dry Wt. Gms.	>2 mm. %	pH	C %	N %	Hexane extr. %
26	4.8	95	21	7.1	3.2	.152	
27	3.0	55	7	7.2	1.7	.061	
28	6.3	170	1	7.4	0.6	.034	
29	8.5	250	2	7.9	0.9	.052	
30	6.0	165	0	8.0	0.6	.034	0.01
31	8.3	265	1	7.6	0.6	.051	
32	3.8	115	0	7.4	0.6	.037	
33	10.5	275	5	8.1	0.6	.069	
34	6.0	85	0	7.7	3.8	.183	
35	5.5	80	1	7.7	3.8	.142	
36	5.8	100	1	7.5	3.5	.121	
37	7.8	143	16	7.4	1.2	.061	
38	8.5	142	6	7.3	1.7	.050	
39	5.5	145	0	7.6	0.8	.049	0.02
40	7.0	140	5	7.8	1.2	.050	
41	2.5	65	1	7.6	0.8	.050	

ll chemical analyses on <2 mm soil; pH as rec'd.

size in percent.

ICIENTS OF FIRST-DEGREE EQUATION

10.85224 - 0.03170 X + 0.00145 Y

ICIENTS OF SECOND-DEGREE EQUATION

-15.45218 + 0.25870 X + 0.34519 Y - 0.00156 X2 + 0.00003 XY - 0.00163 Y2

ICIENTS OF THRID-DEGREE EQUATION

-23.88312 + 0.56581 X + 0.40754 Y - 0.00545 X2 - 0.00033 XY - 0.00178 Y2 + 0.00002 X3 - 0.00001 X2Y +
.00001 XY2 + 0.00000 Y3

ICIENTS OF FOURTH-DEGREE EQUATION

95.87878 + 2.51731 X - 8.92355 Y - 0.03200 X2 + 0.03653 XY + 0.13031 Y2 - 0.00002 X3 + 0.00036 X2Y -
.00030 XY2 - 0.00061 Y3 + 0.00000 X4 - 0.00000 X3Y + 0.00000 X2Y2 + 0.00000 XY3 + 0.00000 Y4

ICIENTS OF FIFTH-DEGREE EQUATION

-486.12331 + 255.81696 X - 267.12065 Y - 3.79962 X2 - 0.80136 XY + 5.36383 Y2 + 0.01497 X3 + 0.05056 X2
0.03341 XY2 - 0.03357 Y3 - 0.00001 X4 - 0.00021 X3Y - 0.00010 X2Y2 + 0.00032 XY3 + 0.00007 Y4 - 0.00000 X4
0.00000 X3Y2 - 0.00000 X2Y3 - 0.00000 XY4 - 0.00000 Y5 .

ERROR MEASURES

CE DEGREE	FIRST	SECOND	THIRD	FOURTH	FIFTH	SIXTH
ARD DEVIATION	9.49	8.39	8.17	7.24	6.98	5.05
TION EXPLAINED SURFACE	0.6105E 02	0.6925E 03	0.8073E 03	0.1267E 04	0.1603E 04	0.2129E 04
TION NOT EXPLAINED SURFACE	0.2884E 04	0.2252E 04	0.2138E 04	0.1677E 04	0.1341E 04	0.8161E 03
VARIATION	0.2945E 04	0.2945E 04	0.2945E 04	0.2945E 04	0.2945E 04	0.2945E 04
ICIENT OF INATION	0.0207	0.2351	0.2741	0.4303	0.5444	0.7228
ICIENT OF LATION	0.1439	0.4848	0.5235	0.6559	0.7378	0.8502

... taken from the ... survey. ...
... and the X coordinate expresses particle size in percent.

OEFFICIENTS OF FIRST-DEGREE EQUATION

= 2.3[illegible] - 0.00[illegible] X + 0.00339 Y

OEFFICIENTS OF SECOND-DEGREE EQUATION

= -3.1[illegible]17 + 0.08269 X + 0.03360 Y - 0.00034 X2 - 0.00015 XY - 0.00007 Y2

OEFFICIENTS OF THIRD-DEGREE EQUATION

= -5.3972[illegible] + 0.15497 X + 0.03722 Y - 0.00094 X2 - 0.00045 XY + 0.00008 Y2 + 0.00000 X3 + 0.00000 X2Y
0.00000 XY2 - 0.00000 Y4

OEFFICIENTS OF FOURTH-DEGREE EQUATION

= 10.22[illegible] - 2.18489 X + 1.82251 Y + 0.03048 X2 - 0.00382 XY - 0.02879 Y2 - 0.00011 X3 - 0.00026 X2Y
0.00[illegible] XY2 + 0.00011 Y3 + 0.00000 X4 + 0.00000 X3Y - 0.00000 X2Y2 - 0.00000XY3 - 0.00000 Y4

OEFFICIENTS OF FIFTH-DEGREE EQUATION

= 37.6[illegible] - 15.18[illegible] X + 10.43765 Y + 0.48[illegible] X2 - 0.25042 XY - 0.14280 Y2 - 0.00457 X3 - 0.00185
0.00[illegible] XY2 + 0.00025 Y3 + 0.00001 X4 + 0.00004 X3Y - 0.00004 X2Y2 - 0.00001 XY3 + 0.00000 Y4 -
0.00000 X5 - 0.00000 X4Y + 0.00000 X3Y2 + 0.00000 X2Y3 - 0.00000 XY$ + 0.00000 Y5

ERROR MEASURES

...FACE DEGREE	FIRST	SECOND	THIRD	FOURTH	FIFTH	SIXTH
...NDARD DEVIATION	1.59	1.33	1.31	1.07	0.90	0.75
...IATION EXPLAINED SURFACE	0.3196E 01	0.3308E 02	0.3547E 02	0.5810E 02	0.7137E 02	0.8106E 02
...IATION NOT EXPLAINED ...URFACE	0.1005E 03	0.7064E 02	0.6825E 02	0.4563E 02	0.3235E 02	0.2266E 02
...L VARIATION	0.1037E 03	0.1037E 03	0.1037E 03	0.1037E 03	0.1037E 03	0.1037E 03
...FICIENT OF ...MINATION	0.0308	0.3189	0.3420	0.5601	0.6880	0.7815
...ICIENT OF ...LATION	0.1755	0.5647	0.5848	0.7484	0.8294	0.8840

Table 5. Visual Description of Grab Samples Collected July - October, 1970

Station	Size	Color	Other Comments
1	medium sand	yellow	clean, uniform
2	medium sand	yellow	clean, uniform
3	silt-clay	dark grey	*Mytilus* shells
4	silt-clay	dark grey	uniform
5	silt, fine sand	grey	benthic animals, wood fragments
6	fine sand	olive	uniform
7A	silt	grey	uniform
7B	sand	olive	uniform
8	silt	dark grey	2 layers, shells
9	silt/sand	gray/olive	*Artica*, animals
10	silt	dark grey	dense
11	silt/silt	grey, black	2 layers, shells, animals
12	sand	yellow	amphipod tubes
13	sandy silt	olive gray	*Arctica*
14	silt/sand clay/silt	grey/grey/black	3 layers
15	silt	black	*Mytilus* shells, coal
16	sand	yellow	black horizon, oyster shell
17	sand	yellow	many animals
18	silt/sand/silt	grey/grey/black	shells
19	sand	olive	uniform
20	silt/silt	grey/black	smooth
21	silt	black	plant detritus, petroleum

Table 5 Con't

Station	Size	Color	Other Comments
22	sand	yellow	uniform, animals
23	silt	dark grey	smooth, uniform
24	silty sand	dark grey	oyster shells
25	silty sand	grey	pebbles, shells
26	sand	olive	*Arctica*, scallop shells
27	silt	dark grey	dense, homogeneous
28	sand	olive	clean, sand dollars, animals
29	silt/sand	grey/grey	2 layers
30	silt	dark grey	dense, uniform
31	sandy silt	grey	soft, uniform
32	sandy silt	olive	uniform
33	silt/sand/clay	brown/black/grey	buried amphipod tubes, worms
34	silt/silty sand	brown/grey	some animals
35	silt/sandy silt	grey/olive	worms
36	silty sand	grey-brown	amphipod tubes
37	silty sand	grey-brown	amphipod tubes

Species	Providence Harbor Ekman dredge 15X15cm pipe dredge PG21	PG22	PG4	PG6	PG1	PS11	PS12	Providence River 1/10M² Smith-McIntyre grab PS31	PS32	PS33	PS41	PS42	PS51	PS52	PS53	dredge c on barge (large a
Arthropoda																
ogammarus mucronatus			1													
gon septemspinosus								2								
monetes pugio			10													
oura polyphemus							*									*
Polychaeta																
mete cretica										3			1	1		
omastus filiformis						13	*	4880	600				920	*	70	
ella canirata						10	*				2	*	1100	600	70	
tulid						23	*									
na affinis							*			1			3	2		
on americanus						1		3					1	1		
nde solitaria						10	*		4	15			1			
ke obscura											68	*				
ys incisa								30	24	29			13	16	15	
s succinea	27	9	2	5	*						15	*				
a virens								1			1					
noria gouldi								53	18	54						
e heteropoda						3	*	1			17	*	5	16		
la sanguinea						1										
aites speciosa						1		10		1			2	1		
loma ligni	3	1			*			3	4	3	138	*	1	3		
filicornis								1								
lospio benedicti	1000+	1000+	100+	1000+	*	29	*	8500	5650		1000+	*	6450	9300	354	
Mollusca																
a limatula									1360						22	
a balthica	2	2		1	*						1					
arenaria	35	22			*				35	2	5	*		3	1	
la lateralis								4220	8700		800	*	320	2660	1560	
naria mercenaria						1	3		5							
on canaliculatum																*
ius trivittatus						3		12	15	87		*		4	12	
ius obsoletus	24	1	50	29	*											
ices duplicata										1						*
Echinodermata																
ias forbesi																*

dicates ( ) the species was present but not counted ( )

	Station																
	7			9			8			10			11			14	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Protozoa																	
Jaculella obtusa	*	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cnidaria																	
Cerianthus americanus	0	0	1	10	5	4	0	0	0	2	0	2	0	0	0	0	0
Edwardsia elegans	0	0	0	52	42	35	0	0	0	1	0	0	2	0	2	0	4
Nemertea																	
Cerebratulus lacteus	0	0	2	10	11	7	0	0	1	2	0	0	3	1	2	2	2
Nemertine sps.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthropoda																	
Ampelisca abdita	0	0	0	11	7	1	0	0	0	0	0	0	0	0	0	0	1
Ampelisca agassizi	20	4	468	0	0	0	0	0	0	0	0	0	717	34	654	2875	16[illegible]
Ampelisca vadorum	2	0	109	0	0	0	0	0	0	0	0	0	2	0	1	0	0
Byblis serrata	251	211	163	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Corophium cylindricum	5	1	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corophium sps.	0	0	1	3	1	0	0	0	0	0	0	0	1	0	0	0	0
Erichthonius hunteri	0	0	2	1	0	0	0	0	0	0	0	0	9	3	16	7	7
Erichthonius difformis	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0
Unciola irrorata	0	0	96	0	0	0	4	0	11	0	0	0	36	4	30	44	59
Leptocheirus pinguis	12	11	83	3	25	0	0	25	0	0	0	0	257	176	339	6	17
Photis reinhardi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0
Photis sps.	0	0	28	16	12	0	0	0	0	0	0	3	6	4	8	2	6
Orchomenella pinguis	0	0	4	0	0	0	0	0	0	0	0	0	7	0	0	52	14[illegible]
Tmetonyx cicada	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lysianassid sps. A	5	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	2
Lysianassid sps. B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Phoxocephalus holbolli	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	17	4
Monoculodes edwardsi	1	0	0	0	0	1	0	0	2	0	0	0	1	0	0	0	0
Stenothoe minuta	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Calliopiid sps.	0	0	0	0	0	0	0	0	0	0	01	2	3	5	1	0	0
Haustoriid sps.	5	7	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dulichia porrecta	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Amphipod sps. A	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Amphipod sps. B	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
Amphipod sps. C	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0

	Station																
		7			9			8			10			11		14	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Arthropoda (con't.)																	
Ptilanthura tenuis	4	2	18	0	0	0	0	0	0	0	0	0	3	0	1	16	13
Cirolana concharum	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Edotea triloba	0	0	0	2	3	6	0	0	0	0	0	0	0	0	0	0	0
Edotea spp.	0	0	*	0	0	0	0	0	0	0	0	0	*	*	*	0	0
Diastylis quadrispinosa	0	0	0	0	2	1	0	3	0	0	0	0	0	0	2	15	9
Diastylis sculpta	1	0	9	2	5	9	0	0	0	0	0	0	21	5	10	13	21
Eudorella hispida	0	0	112	7	2	12	0	5	1	0	0	0	60	5	28	66	79
Lamprops quadriplicata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Penaeus brasiliensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cancer spp. (megalops)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
Balanus amphitrite neveus	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0
Ostracod spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Polychaeta																	
Drilonereis longa	0	0	0	5	6	4	0	0	0	0	0	0	0	0	1	4	2
Ampharete arctica	0	0	0	3	5	6	1	0	0	5	0	0	4	0	5	0	4
Heteromastus filiformis	0	0	36	2	4	0	0	5	0	22	35	218	36	0	42	4	7
Capitella capitata	1	0	5	0	0	0	0	0	0	0	0	0	1	0	4	7	4
Cirratulid	0	0	0	8	3	15	0	0	0	0	0	0	0	0	0	0	0
Tharyx acutus	13	13	62	0	0	0	0	5	0	28	27	188	179	40	155	6	7
Pherusa affinis	0	0	1	34	18	24	0	1	0	0	0	0	5	3	10	2	2
Ophioglycera gigantea	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrineris tenuis	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrineris fragilis	1	1	0	13	15	22	0	0	0	0	0	0	0	0	0	0	0
Ninoe nigripes	0	0	0	7	25	7	0	11	0	8	0	3	26	20	39	5	4
Clymenella torquata	5	7	13	42	21	5	0	0	0	0	0	0	25	0	4	3	1
Aglaophamus circinata	14	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nephtys caeca	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nephtys incisa	0	0	0	12	7	8	1	32	1	36	37	45	8	40	40	3	3
Nereis spp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
Ammotrypane aulogaster	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
Scoloplos acutus	3	0	13	5	6	5	0	0	0	0	0	0	0	0	0	3	1
Owenia fusiformis	0	0	1	16	0	12	0	0	0	0	0	0	0	0	1	3	2
Aricidea jeffreysii	2	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pectinaria gouldii	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

	Station																
	7			9			8			10			11			14	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Polychaeta (con't.)																	
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
Eteone lactea	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Eteone longa	0	0	0	0	0	0	0	0	0	0	13	23	21	5	16	1	2
Paranaitis speciosa	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Phyllodoce mucosa	1	2	11	0	0	0	0	0	0	0	0	0	5	1	3	6	2
Harmothoe extenuata	0	0	0	0	0	0	0	0	0	3	1	5	8	9	15	10	6
Euchone rubrocincta	0	0	0	4	1	0	0	0	0	0	1	1	5	0	6	0	0
Potamilla reniformis	0	0	0	4	3	3	0	0	0	0	0	0	0	0	1	1	0
Chone infundibuliformis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2
Sabellariid spp.	0	0	0	6	13	2	0	0	0	4	0	1	29	6	15	0	1
Scalibregma inflatum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Pholoe minuta	11	3	38	29	8	9	0	0	0	0	3	0	15	4	33	10	1
Orbinella limicola	2	4	2	0	0	0	0	0	2	0	0	0	0	0	2	0	1
Laonice cirrata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polydora quadrilobata	0	0	0	5	0	1	0	0	0	0	0	0	14	0	3	0	0
Prionospio malmgreni	0	0	14	0	3	0	0	4	0	11	3	54	66	28	153	46	7
Spio filicornis	8	1	2	1	0	0	0	0	0	5	2	9	1	0	1	0	0
Spiophanes bombyx	13	10	28	0	2	0	0	0	0	0	0	0	2	0	3	3	1
Streblospio benedicti	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
[illegible] acutata	0	0	0	11	8	12	0	0	0	0	0	0	0	0	0	0	0
Clymenella torquata	0	0	45	0	0	0	0	0	0	0	0	0	2	0	2	3	5
Polycirrus spp.	0	0	0	34	12	21	0	0	0	4	0	0	2	0	1	0	0
Terebellides stroemi	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Molluscs																	
Nucula delphinodonta	0	0	0	49	51	34	0	0	0	0	0	0	0	0	0	0	0
Nucula proxima	2	0	3	102	153	143	0	0	0	1	0	0	3	3	0	2	8
Yoldia limatula	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma calcarea	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Tellina agilis	2	0	2	1	0	0	1	0	0	0	2	1	10	1	3	0	0
Ensis directus	0	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyonsia hyalina	0	0	0	0	0	0	0	0	0	0	0	0	4	0	3	0	0
Mulinia lateralis	0	0	1	0	0	0	15	33	2	6	14	17	0	0	0	0	0
Spisula solidissima	0	0	1	0	0	0	0	0	0	0	0	4	13	0	21	0	0

	7			8			9			10			11			12	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Mollusca (con't.)																	
Pitar morrhuana	0	0	0	3	4	5	0	0	0	14	2	0	2	2	6	0	1
Arctica islandica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Astarte borealis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Astarte undata	0	0	0	1	4	3	1	0	0	4	4	3	3	0	3	0	0
Cerastoderma pinnulatum	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Divaricella quadrisulcata	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Periploma papyratium	0	0	0	31	48	49	0	0	0	0	0	0	0	0	0	1	0
Cylichna alba	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lunatia heros	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Mitrella lunata	6	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius trivittatus	0	0	1	0	0	0	3	1	0	0	0	0	0	0	0	0	1
Pyramidellid spp.	0	0	0	10	10	10	0	0	0	0	0	0	0	0	0	0	0
Echiurida																	
Echiurus pallasii	0	0	0	0	0	0	0	0	0	0	0	0	6	0	1	0	0
Echinodermata																	
Asterias vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Echinarachnius parma	3	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thyone scabra	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Phoronida																	
Phoronis architecta	0	0	3	0	0	0	0	2	0	38	10	23	8	31	13	0	2
Chordata																	
Bostrichobranchus pilularis	0	0	0	12	10	5	0	0	0	0	0	0	0	0	0	0	0
Number of individuals	426	351	1451	576	562	484	27	131	23	196	154	603	1163	438	1712	3272	1999
Number of species	29	25	49	41	41	35	8	14	10	20	14	19	53	26	49	44	46

indicates presence of species too small or too abundant to count

Table 8 Sediment Characteristics of the 1/10 M^2 Biological Samples

Station	Depth (Feet)	Visual Description	Loss on Ignition (%)	Median Particle Size (mm)	Sorting Coefficient
7-1		Clean yellow sand	-	-	-
7-2	90	Clean yellow sand	1.0	0.25	1.30
7-3		Tubes on olive/yellow sand	1.5	0.21	1.39
9-1		Grey/black silt,	-	-	-
9-2	106	surface oxidized,	4.0	0.06	1.13
9-3		fine worm tubes	4.0	0.06	1.27
8-1		Coarse grey sand/shells	0.6	0.350	2.97
8-2	96	Sand/silt/soft clay	3.0	0.062	2.83
8-3		Coarse grey sand/shells	-	-	-
10-1		Sand/silt/clay,	3.7	0.030	2.58
10-2	99	oil droplets,	3.6	0.035	2.23
10-3		varved sandy clay	3.0	0.042	2.32
11-1		Silt/dense clay, tubes	-	-	-
11-2	98	Silt/brown clay	3.4	0.25	2.71
11-3		Silt/pebbles/clay, tubes	2.8	0.15	2.53
14-1	100	Olive sand,	2.2	0.13	1.54
14-2		many amphipod tubes	2.0	0.10	1.49

APPENDIX I - Trend Surface Analysis

Because of its wide potential use in the analysis of quantitative changes in sea floor characteristics it seems worthwhile to briefly describe numerical surface techniques and contour plotting as used in this report. A procedure known as trend surface analysis, previously utilized in geological studies, has been utilized. The specific program modified for use on the University of Rhode Island's IBM 360/50 system was described in detail by O'Leary, Lippert and Stitz (1966).

In the above mentioned program, trend surface analysis is carried out by least-squares surface-fitting techniques using orthogonal polynomials to irregularly or regularly spaced data points. For a set:

$$P_o(X,Y), P_1(X,Y), P_2(S,Y), \ldots P_q(X,Y)$$

of orthogonal polynomials, the polynomials have the following relationship:

$$\sum_{i=1}^{N} P_r(X_i,Y_i) \quad P_s(X_i,Y_i) = 0, \text{ where } r \neq s$$

In other words, with r not equal to s, the sum of the products of the orthogonal polynomials in X and Y is zero. The theory of orthogonal polynomial technique is advantageous in this case because of: a) faster computer solution, and b) greater flexibility in choice of polynomial terms. It should be appreciated that the procedure is used to describe dominant features of surfaces.

Sample locations can be defined by two orthogonal geographic coordinates (independent variables, U and Y). Then sample locations for which some variable Y_n were observed can be projected onto a computed mathematical surface, Y_n - F(U,V). That is, ordinates may be erected at each U,V location with heights proportional to the quantitative value of the property measured (the dependent variable, Y). In this way, points representing Y are located in 3 dimensions and the variability of Y can be approximated by the mathematical surface.

Various types of functions could be utilized to approximate the surface, but polynomials have been used most frequently. The present program uses the polynomial formula:

$$Y_n = a_o + a_1U + a_2V + a_2U^2 + a_5V^2 + a_6V^3 + a_7U^2V + \ldots\ldots$$

To obtain coefficients of the surface which most closely approximate the observed data, the method of least squares is used. In practice surfaces of successively high degree are applied. The linear (1st degree) surface is:

$$Y_n = b_o + b_2U + n_2U$$

The linear plus quadratic surface (2nd degree surface) is:

$$Y_n = C_o + C_1U + C_3U^2 + C_4UV + C_5V^2$$

Successive surfaces of higher degree acount for larger and larger portions of the total sum of the squares of the observed data values (Y_n). That is, more and more of the variance is being explained. The percentage of the total sum of squares accounted for by a surface represents a measure of the closeness or goodness of fit of a particular surface.

Reference

[illegible], M., R. H. Lippert and O. T. Spitz, 1966. Fortran IV and MAP program for computation and plotting of trend surfaces for degrees 1 through 6. Computer Contrib. No. 3, Kansas Geol. Survey, Univ. of Kansas.